I dedicate this disertation
to
my beloved mother and father

Interactions between *Anystis baccarum* (Acari: Anystidae), a generalist predatory mite, and larvae of *Epiphyas postvittana* (Walker) (Lepidoptera: Tortricidae), a pest of apples

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ABSTRACT

A large numbers of Anystis baccarum (Acari: Anystidae) were discovered living alongside of Epiphyas postvittana (Lepidoptera: Tortricidae) larvae known as light brown apple moth (LBAM) in shelter belt of acacia, Acacia rewa (Leguminoseae: Sub family Mimosoidae). Few questions that needed to be answered were whether the mites actually feed on the LBAM larvae and what are their interactions. The objective of my study was to investigate the general characteristics of mite feeding on LBAM larvae, and to study the age, density, webs and defence behaviour of larvae as exogenous factors, and the effect of level of starvation and experience of mites as endogenous factors on foraging behaviour of A. baccarum.

Eleven experiments were conducted under laboratory conditions. At 20 c, the average daily consumption rate of A. baccarum was 11.5±2.68 neonate E. postvittana larvae of 1.484 mm in lenght and 0.231 mm in width. The predator spent 1106± 309 seconds mean feeding time, feeding on a neonate larvae of E. postvittana. A. baccarum is cannabalistic and survived 6.1±2.28 days totaly deprived of food and water.

Webs of E. postvittana larvae act as a physical barrier to attack of A. baccarum. When the webs were removed larvae upto eight days of age were consumed by A. baccarum, however survival from capture by mite increased with age. When the mite was given a choice between three different age groups of larvae, a higher number of neonate larvae were taken as the first choice, but the overall results showed the choice depends on random encounters between the predator and prey and prey avoidence behaviour of larvae. Spinning was the most frequent avoidence behaviour of larvae without webs. Spinning response occured less frequently with increased age of the larvae. The most common response of larvae in webs was quick movement forwards or backwards.

Starvation for 24 hours did not significantly increase walking speed of A. baccarum over walking speed of non-starved mites, but walking speed was decreased at 48 hr and 72 hr starvation. However, starvation increased prey capture of A. baccarum compared to non starved condition. Starvation also had a significant effect on number of captures at first encounter.

A. baccarum with no experience of prey on apple shoots prefered to rest on branch of apple than leaf and fruit given that area of the branch is low, preference was even greater. On their search of alternative walking and resting periods, A. baccarum spent significantly more time walking than resting. When given experience of feeding a neonate larva of LBAM on branch, leaf or fruit, A. baccarum spent significantly more time walking on the location they were fed.

In conclusion, the larvae of E. postvittana includes in to the list of prey of A. baccarum. If encounterd during their dispersal phase after hatching, possibilities are high that neonate larvae of E. postvittana to be preyed by A. baccarum ocurring in large numbers in orchrd ecosystems in New Zealand. Studies on this predator-prey interaction opens new venues of research on generalised predator-prey interactions.

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CHAPTER 1

LITERATURE REVIEW OF MITES AS BIOLOGICAL CONTROL AGENTS

1.1 Introduction

In many parts of the world, predatory mites are currently being evaluated as control agents against leaf-feeding insects and mites. This interest in using predatory mites as biological control agents is fairly recent. Three decades ago most of the acarines now being considered as biological control agents against leaf-feeding insects had not even been identified. The first mite recognized for its ability to reduce pest populations (reviewed by Gerson and Smiley, 1990), was Hemisacroptes malus (Shimer), which feeds on the oyestershell scale, Lepidosaphes ulmi (L.), reported from America in 1868. They noted that the first international shipment of these mites as natural enemies was undertaken in 1873 following redocumentation of the importance of the mite by C.V. Riley in the same year. The project of transfering predatory mites to from eastern Canada to western Canada in 1917 control the same prey was rated as a successful biological control project by Turnbull and Chant (1961). The Bdellid mite, Bdellodes lapidaria Kramer, was discovered (Womersley,1933) as a predator of the lucerne flea, Smithurus viridis (L.), in Australia. Uchida and Miyazaki (1935) considered water mites as important enemies of mosquitoes. Thereafter many species of predatory mites were recognised as important biological control agents by scientists all over the world.

Although Acari were identified for their potential use against some pests from the beginning of the rise of biological control as a discipline, it was only from the 1950's onwards that the potential of the Phytoseiidae and other mites was recognized and mites began to draw the attention they deserve as biocontrol agents. Table 1 summarises important mites which provide control of agricultural pests. Many applied studies including introductions of predatory mites to control different pests have also been done.

In 1982, the Berkeley Conference on biological control of pests by mites was held. The following recommendations were made by contributers to the conference (Gerson and Simley, 1990): (1) that further exploration for predaceous mites be undertaken as well as basic research on mite systematics and biology, (2) that mass rearing methods and quality control be developed, (3) that field experiments employing appropriate controls be conducted on promising candidates, (4) that better (and more uniform) evaluation procedures be devised, and (5) that means of integrating the emerging, promising acarine biocontrol agents into existing pest management programmes be developed.

1.2 Systematics of predatory mites

The Class Arachnida is comprised of eleven divisions. All but two of these are completely predaceous in habit, with representatives often displaying a variety of morphological characteristics well suited to a predatory existence (Krants,1975). In the subclass Araneae (spiders), the head and thorax are combined in a single unit, the cephalothorax, jointed to the abdomen by a slender pedicel. The subclass Acari includes the ticks and the mites. The acarine body (Krants,1975) is composed mainly of the idiosoma, while mouth-parts are borne on the gnathosoma, an anterior region more or less distinct from the idiosoma. All the acarine biological control agents belong to order Acariformes and order Parasitiformes. The important suborders to which they belong are Crytostigmata, Astigmata, Prostigmata, and Mesostigmata.

Table 1. Some mites which provide control of agricultural pests (source-Gerson and Smiley, 1990 p. 142, modified).

Mite Family	**Natural enemy**	**Pest**	**Pest order**	**Habitat**
Anystidae	Anystis spp	Earth mite	Prostigmata	Pastures
		Lucerne flea	Collembola	Pastures
Ascidae	Blattisocius	Ephestia	Lepidoptera	Stored products
Bdellidae	Bdellodes spp	Lucerne flea	Collembola	Pastures
Cheyletidae	Cheyletus spp	Acarids	Prostigmata	Stored products
Hemisarcoptes	Hemisarcoptes	Armoured scale insects	Homoptera	Orchards
Macrochelidae	Macrocheles	Bush flies	Diptera	Cowdung
Phytoseiidae*	Amblyseius fallacis	European red mite	Prostigmata	Orchards
		Two spotted spider mite	Prostigmata	Orchards
Phytoseiidae	Euseius	Citrus thrips	Thysanoptera	Orchards
Phytoseiidae	Phytoseiulus persimilis	Spider mites	Prostigmata	Green houses
Phytoseiidae*	Typhlodromus occidentalis	Two spotted spider mite	Prostigmata	Orchards
Phytoseiidae	Typhlodromus pyri	Spider mites	Prostigmata	Orchards
Stigmaeidae	Stigmaeids	Brevipalpus	Prostigmata	Tea

*(Early,1984)

Records on common predatory mites belonging to 29 acarine families were reviewed by Gerson and Smiley (1990) and are summarised in Table 2. Information on recently recorded predatory mites are included with the relevant references.

The literature on predatory mites is voluminous but it has recently been condensed (Gerson and Smiley, 1990) and largely concerns the usefulness of one family, the Phytoseidae, in the control of spider mites in horticultural crops. In the Canary islands, Pande et al. (1989) report of seven species of tetranychid mites together with data on 4 species of predatory phytoseiids associated with them. Kreiter et al. (1991) on the other hand reviewed the predatory mites which are found in viticulture and fruit tree culture.

1.2.1 Recent studies on biology

The study of the biology of predatory mites is a prerequisite for applied studies. Abou-Awad and Reda (1992), showed fecundity of frequently mated females of predatory mite Agistimus exsertus was greater than females mated only once. A positive relationship was noted between the number of progeny and sex ratio at different intervals of the reproductive period. Kreiter (1991) described the biology, morphology, behavior and occurence of 36 phytoseiid predators that occur in France.

Table 2. Common features of predatory mite families, predatory mites recorded, and their hosts.

Family	Common Features	Predatory mite species	Hosts
Acaridae	Whitish, slow moving, many species associated with arthropods, commonly occur in stored foods.	Tyrophagus putrescentiae	Arthropods in stored grain, cheese, fungus cultures.
		Rhizoglyphus echinopus	plant parasitic nematodes
Anystidae	Large, reddish, soft bodied, fast runners, carry few dorsal setae, possess a palpal thumb-claw complex, prey on mites and small insects,	Anystis agilis	Many pests infesting alfalfa, apple and citrus orchards, and vineyards
		Anystis baccarum	Spider mite
		Anystis salicinus	red-legged earth mite, lucerne flea
Arrenuridae	Heavily sclerotinised bodies	Arrenurus spp.	Mosquitoes

Family	**Common Features**	**Predatory mite species**	**Hosts**
Ascidae	Free living predator Commonly found in soils, on plants and in stored products	Blattisocius tarsalis	Stored product pest moth
		Arctoseius cetratus	Mushroom pests
		Platyseius spp.	Mosquito egg and larvae
		Cheiroseius spp.	Mosquito egg and larvae
		Lasioseius parberlesi	Mite pest of rice
		L. scapulatus	Nematodes
Bdellidae	Snout-like mouthparts, fairly large in size (4 mm), red-brown or greenish, active hunters.	Bdella depressa	Spider mites, spring tails
		B. longicornis	vine spider mite
		B. lapidaria	Lucerne flea

Family	**Common Features**	**Predatory mite species**	**Hosts**
Camerobiidae	Long legs, weak palpi.	*Neophyllobius* spp.	Armoured scale insects European fruit scale Eriopalpid mites Tenuipalpid mites
Cheyletidae	Slow moving, some are ectoparasites of birds, mammals or insects, some are free living predators.	*Cheyletus eruditus*	Mite pests of stored foods
		Hemicheyletia bakeri	Spider mites
		Cheletogenes ornatus	Armoured scale insect crawlers
Cunaxidae	3-5 segmented palpi, yellow, red or brown in colour, fast runners, indiscriminate feeders on small arthropods	*Cunaxa capreolus*	Book lice, oriental spider mite
		C. parvus	Oyster shell scale
		C. oliveri	Eriophyid gall mite

Family	Common Features	Predatory mite species	Hosts
Eriophyidae	Elongate, worm like bodies, two pairs of anteriorly placed legs, claw-less tarsi.	Aceria chondrillae	Skeleton weed
		Aceria app.	Russian knapweed
		A. convolvuli	Bind weed
		Eriophyes boycei	Rag weed
Erythraeidae	Large, reddish mite, larvae usually parasitize other arthropods, nymphs and adults are predators	Lasioerythraeus johnstoni	Tarnished plant bug
		Balaustium putmani	Many arthropods
		B. murorum	Egg predator of apple tortricid
Eupalosellidae	Very long palpi and chelicerae, yellow to orange coloured mites, usually occur on plants, often associated with armoured scale insects, a few species occur in the soil.	Saniosulus nudus	scale crawlers

Family	**Common Features**	**Predatory mite species**	**Hosts**
Galumnidae	Genital setae carry six setae on each plate.	Orthogalumna tetrabantis	Water hyacinth
		Pergalumna spp.	Nematodes
Hemisarcoptidae	Whitish, soft-bodied mites.	Hemisacroptes coccophagus	Armoured scale insects
		H. malus	Oyster shell scale
Hydryphantidae	Red, water mites with soft, papillate or lined integument	Hydraphantids (parasites)	Mosquitoes, black flies, biting midges, horse flies.

Family	**Common Features**	**Predatory mite species**	**Hosts**
Laelapidae	Blood-sucking parasites of birds and mammals and nest-inhabiting or free living predators of small invertebrates.	Androlaelaps Stratiolaelaps *Hypoaspis aculeifer*	Western corn rootworms plant nematodes
		Hypoaspis spp	*Oryctes rhinoceros*
		Haemogamasus pontiger	Acarid mites, wounded or weakly sclerotized insect larvae
Limnesiidae	weak integument	*Tyrrellia circularis*	Biting midges
		Limnesia jamurensis	Anopheles and culex mosquitoes

Family	Common Features	Predatory mite species	Hosts
Macrochelidae	Fast-moving, free- living predators common in habitats rich in decaying organic material.	Macrocheles muscaedomesticae	House fly, lesser housefly
		M.glaber	Australian bushfly
		M. peregrinus	Bushfly, buffalofly
Parasitidae	Common predators in the soil, often dispersed by beetles and flies.	Pergamasus quisquiliarum	garden symphylan
		Poecilochirus monospinosus	
		Pergamasus spp.	House fly Stored product pest mites

Family	Common Features	Predatory mite species	Hosts
Phytoseiidae	Entire dorsal shield with 20 pairs of setae, fast-running mites live on plants and in the soil, feed on small arthropods (including spider mites), on other available diets such as homopteran honey dew, pollen and rarely plant juices.	Phytoseiulus persimilis	Spider mites
		Typhlodromus occidentalis	Spider mites
		T.pyri	Spider mites
		Amblyseius spp.	Cyclamen mite
		A. victoriensis	Citrus eriophyids
		A. cucumeris	Thrips tabaci
Pionidae	Weak, smooth integument (parasitic)	Pionia larvae	Chironomidae
		Piona nodata	Mosquito larvae
		Piona spp	Small aquatic arthropods

Family	Common Features	Predatory mite species	Hosts
Padapolipidae	All members are parasites of insects	Lacustacarus spp.	Short horned grasshopper
		Padapolipiodes grassi	Migratory locust
		Chrysomelobia labidomerae	Chrysomelid beetle
		Coccipolipus epilachnae	Mexican bean beetle
Plarygosomatidae	Red, small-to mediun sized parasites of lizards, scorpions and various insects.	Pimeliaphilus plumifer	Blood sucking bugs
		Pimeliaphilus spp.	Cockroaches
Pseudocheylidae (van Dis and Ueckermann, 1991)	Predatory mites ocurring under tree barks, in litter and moss.	Pseudocheylus spp.	(Information not available)
		Neocheylus spp.	
		Anoplocheylus paraclavatus	
		A. tellustrus	
		A. reticulatus	

Family	**Common Features**	**Predatory mite species**	**Hosts**
Pyemotidae	Milky-white spindle shaped or rounded, segmented bodies (parasites)	Pyemotes herfsi	Caterpillars of the pink ball worm
		P.tritici	Stored food pest-Tribolium
Stigmaeidae	Red to yellow colour, ovoid or elongate shaped, live in the soil and on plants, usually predators of mites, a few prey on scale insects or parasitises flies	Agistemus spp. Zetzellia spp.	Eriophyid, tetranychid, tenuipalpid mites.
		Several stagmeids	Tenuipalpid
Tarsonemidae	Small mites with broad to elongated oval bodies, hard and shiny integument, Feed on green plants, fungi, arthropods as parasites, predators or as undetermined relationship.	Iponemus spp. (parasite)	Bark beetle
		Acaronemus destructor	Phytophagous mite of Tenuipalpidae and Tetranychidae

Family	Common Features	Predatory mite species	Hosts
Tetranychidae	Needle-like chelicarae	*Tetranychus desertotum*	Prickly pear
		Tetranychus spp.	Water hyacynth
		T. lintearius	gorse
Trombidiidae	Large in size, usually red in colour, dense coat of setae.	Eutrombidium locustarum (parasites and predators)	Many acaridid, tettigonid grasshoppers.
		Allothrombium monspessulanum	Aphids
Tydeidae	Small, softbodied, with needle-like chelicerae, fast moving, commonly found in soil and plants, Tudeids play three seperate beneficial roles (1) prey certain pests, (11) serve as alternate food for other predators, (111) 'clean up' honey dew and reduce damage attributed by sooty-mould.	*Homeopronematus anconai*	Tomato russet mite, pollen, fungi, plant tissue.
		Other tydeids	Eriophyids, nematodes, other invertebrates

Family	**Common Features**	**Predatory mite species**	**Hosts**
Uriopodidae	Live in forest and other rich organic soils and in manure, many species disperse during their deutonymphal stage, when attach to insects by means of an anal pedicel.	Fuscuropoda vegetans	Nematodes, house fly, eggs of little house fly.

1.2.1.1 Effect of Temperature and Humidity on Growth and Development

Temperature and relative humidity influence growth and development stages of mites. For example, the biology and life tables of Galendromus helveolus were studied (in relation to temperature) using Eotetranychus sexamaculatus as the food source on Florida citrus by Caceres and Childers (1991). The optimal temperature range for development was between 25°C and 20°C. In the Po Valley of Italy, it was found that diapausing females of the predatory mite Amblyseius antersoni arise from eggs laid during the period, when the photophase lasts approximately 13 h and the average scotophase temperature rarely goes over 14°C (Ivancich, 1990). An increase in relative humidity reduced the days required to suppress prey population of Tetranychus kanzawai by predator Amblyseius longispinosus while an increase in temperature increased the number of days required (Nakagawa 1991).

1.3 Ecology of predatory mites

1.3.1 Population dynamics

Studies on the population dynamics of predator-prey systems facilitates the evaluation of control agents. In studies of population fluctuations in a continuous predator-prey system consisting of Tetranychus urticae and its predator Typhlodromus occidentalis in small orchards in the Australian Capital Territory (van Klashorst et al.,1992), two types of fluctuations were observed: large amplitude fluctuations associated with synchrony of the local cycles and small amplitude fluctuations associated with periods when local population cycles were out of phase. Models have been used by Jansen and Sabelis (1992) to study population dynamics of predatory mites. Here models were formulated in terms of differential equations to understand how patchiness influences population dynamics of a tri-trophic interaction. The stability and distability of the system was discussed. However, Xia (1989) showed two species of predaceous phytoseiid mite, Amblyseius newsami and A. nicholsi, were able to control the prey population (Panonychus citri) effectively. The density of the prey population and the age of the prey had effects on the performance of predator species. Clements and Harmsen (1992) used a simulation model to examine the interactions between predatory mites of two families, the Stigmaeidae and Phytoseidae, that feed on phytophagous apple mites. At low prey densities stagmeids held an advantage over phytoseiids in terms of efficiency because of their higher preference for prey eggs, higher oviposition relative to prey consumption and the ability to consume their own eggs. At higher prey densities, the higher maximum predation rate of the phytoseiids gave them a higher efficacy. Thus the weaker predator (the stagmeid) was the more effective competitor at low prey densities. Using simulation models, a combination of stagmeids and phytoseiids was shown to have greater efficacy than either predator alone over a wide range of prey densities.

1.3.2 Leaf morphology and predators

Host plant characteristics can have a strong effect on the performance of the natural enemies attacking the pests of these plants (Price et al., 1980). Such effects may directly influence the natural enemy or may have an indirect influence through the prey. Such predator enhancement may complement plant allelochemical defences. For example, Leaf surface texture can affect the performance of acarine predators. Leaf domatia, minute cavities frequently located at the junctions of primary and secondary veins on the underside of dicot leaves, often harbour various predaceous mites (Pemberton and Turner, 1989). Walter and O'Dowd (1992) also showed that leaves with domatia generally had higher number of phytoseids, especially their eggs, than those without domatia. In this study, when leaf domatia of a rainforest tree, Elaecarpus reticulatus, were covered with a bitumen paint, a 24% reduction of mites was observed. However, Anystis baccarum(L.), provided far better control of spider mites on glabrous berry leaves than on hairy soybean leaves (Lange et al.,1974a). It was not clear which of these plants is its host plants of spider mites. These results highlight the fact, that interactions between predaceous mites and their pest prey should be studied on the wild plants on which they occur in nature (Gerson and Smiley, 1990). Data on such interactions could assist in predicting the performance of exotic acarine biocontrol agents and would help plant breeders selecting traits which enhance the ability of commercial plant species to obtain protection via natural enemy 'body guards' (Dicke and Sabelis, 1988).

1.4 Behaviour of predatory mites

1.4.1 Generalist vs Specialist

As far as prey preference is concerned, mites are typically classified as either generalist and specialist feeders. Infact most mite predators fall somewhere along a continuum, one extreme of which is represented by specialist feeders like Phytoseiulus persimilis, the other by generalist predators like Anystis species. The location of other mite species on the continuum depends on internal and external factors such as age, ambient humidity, temperature and light conditions (van Houten et al., 1988), the availability of different diets, the nature of the most recent meal (Congdon and McMurtry, 1988). Reported observations on the specificity (and non-specificity) of efficient acarine natural enemies suggests 'specificity' should be viewed in a more dynamic way (Gerson and Smiley, 1990). However, in general, little is known about the pery preferences of generalist predatory mites.

1.4.2 Food (prey) preference

Food preference affects the development, life span and fecundity of predatory mites and depends on many factors. Rasmy et al. (1991) reported Tetranychus uriticae as a suitable prey for Phytoseiulus persimilis because predators matured quickly and females exhibited a high rate of reproduction. However, when fed with Brevipalpus pulture and Eriophyes dioscoridis, P. persimilis developed only to protonymphal stage and (only a few mites developed to adulthood) and thus failed to oviposit. Hypoaspsis vacuus, on the other hand, developed successfully from the larval to the adult stage on eggs of Musca domestica and nymphs of the acarid mite Rhizoglyphus echinopus in the laboratory; however, housefly eggs were the more suitable diet, prolonging adult lifespan to 76.8 days and increasing female fecundity to 1.3 eggs/female per day (Abou-Awad et al., 1992).

Several experimental tests of the hypothesis that natural selection favors predators that search for and select prey species that are more profitable have been conducted. Santos (1991) reported that stigmaeid predator Zetzellia mali does not search and select prey that are more profitable. Rather, the correlation coefficient of Z. mali and its two prey species, Aculus schlechtendali and Panonychus ulmi, revealed that the predator-prey association depended on season and type of prey. It also revealed that in a natural ecosystem, Z. mali responds more to the density of A. schtendali than to the density of P. ulmi. The author proposed the term 'associated response' to describe the ecological process that quantifies the association of predator and prey.

Models can be used to generate ideas for experiments on prey selection behaviour of predatory mites. Dicke et al. (1989) analyzed prey-selection behaviour of the phytoseiid Thyphlodromus pyri using a model and a real experiment. They used two types of prey, adults of apple rust mite, Aculus schlechtendali, and larvae of the European red mite, Panonychus ulmi. The parameter values were determined by fitting the model to the predation rates in monoculture (each species of prey reared seperately with the predator). A large discrepancy was observed between calculated and experimentally determined predation rates of T. pyri in mixed cultures (both species of prey were reared with the predator): the predators actually killed 3-7 times more larvae of P. ulmi than was predicted by the model. The authors suggested that the prey selection behaviour of the predator was different when prey species were presented together than when presented singly and that T. pyri prefers P. ulmi to A. schlechtendali.

The development and reproduction of mites is affected by the type of food they consume. When the predators, Amblyseius aberrans and A. finlandicus were offered two prey species, Tetranychus uriticae, Cecidophyopsis ribis, and pollen of apple, cherry and birch (Betula), feeding on the prey species C. ribis resulted in the shortest development and highest oviposition rates in both phytoseiid mites (Schausberger,1992). However, pollen also had a high value as a food source and when fed upon solely led to complete development and successful reproduction. Rijn and Sabelis (1990) showed that a diet of sweet pepper (Capsicum annum) pollen assisted the survival, development and fecundity of the predatory mite Amblyseius cucumeris, a biological control agent against Thysanoptera in green houses. When the pollen was present on crop leaves, adult female A. cucumeris were also less likely to disperse.

1.4.3 Infochemicals

An infochemical is a chemical that, in the natural context conveys information in an integration between two individuals, evoking the receiver a behavioural or physiological response (Dicke et al.,1990a). These can be pheromones or allelochemicals. A pheromone is "a substance that is secreted by an animal or plant to the outside that cause a specific reaction in a receiving individual of the same species". Allomones and kairomones are two different types of allelochemicals. An allomone is "a substance, produced or acquired by an organism, which, when it contacts an individual of another species in the natural context, evokes in the receiver a behavioral or physiological reaction adaptively favorable to the emitter but not to the receiver". A kairomone is "a substance produced, aquired by, or released as a result of the activities of an organism, which, when it contacts an individual or another species in the natural context, evokes in the receiver a behavioral or physiological reaction adaptively favorable to the receiver but not to the emitter".

Yasui (1992) studied the existence of sex pheromones eliciting precopulatory mate-guarding behaviour in a male predatory mite Macrodheles muscaedomesticae. The author concluded that the deutonymphal female probably does not produce a chemical that attracts males over distances. Rather the sex pheromone of the deutonymphal female occurs as a chemical on the body surface which is soluble in ether and acts as a male arrestant.

Price et al. (1980) and Price (1981) explained tritropic interactions between plants, herbivores and their natural enemies, and the active and passive involvement of plants, in predator-prey interactions. Since the first report on volatile kairomones in interactions between phytophagous mites and predatory mites (Dicke and Sabelis, 1988, Sabelis and Van de Baan, 1983), much information has been gathered on many aspects of acarine allelochemicals and the behavioural responses of mites to plant chemicals. For example, in 1989, Dicke et al. isolated and identified volatile kairomones emitted from lima bean plants (Phaseolus lunatus). They showed that the response of Amblyseius potentillae to two kairomone components was affected by the diet upon which the predator was reared. When reared on a carotenoid-deficient diet, the predator responded to the volatile kairomone of T. uriticae; However, when reared on a carotenoid-containing diet there was no response. Similarly, the phytoseiid predator Amblyseius potentillae responded to volatile kairomones emitted from leaves infested by the two-spotted spider mite (Tetranychus uriticae), the apple rust mite (Aculus schlechtendali) or the thrip (Frankliniella pallida) only when the predator had been reared on a carotenoid-free diet (Dicke and Groeneveld,1986). However, In the same study, the response of A. potentillae to the Europeon red spider mite (Panonychus ulmi) occured regardless of whether A. potentillae was reared on a carotenoid-containing or a carotenoid-free diet. Carotenoids are indispensable for diapause induction in A. potentillae. Hence, carotenoid-deficient predators can increase their fitness by feeding from a carotenoid source. This may explain the response of carotenoid-deficient predators to the kairomones of the two-spotted spider mite.

Volatile chemicals are emitted from artificially-damaged or T. uriticae infested lima bean plants (Dicke, 1988; Dicke et al., 1990). Four compounds that attracted P. persimilis females were identified in the headspace of T. uriticae-infested lima bean plants but were not found in the headspace of undamaged or artificially damaged plants. These four volatile chemicals not only influenced predator behaviour, but also prey behaviour and even the attractiveness of nearby plants to predators (Dicke et al., 1990). The authors suggested that spider mites might control production of the infochemical to inform conspecifics about local density and thus about food quantity and prospects for competition. However, spider mites may prefer nonvolatiles to volatiles to avoid risks of attracting predatory mites. The plant may control the production of volatiles to recruit predatory mite "bodyguards".

The responses of the predators Phytoseiulus persimilis, Phytoseius finitimus and Amblyseius gossipi to volatile infochemicals emitted by three herbivorous mites, and previously infested leaves were studied (Rasmy et al. 1991). The authors suggested that semiochemicals produced by Brevipalpus pulcher acted as kairomones for Phytoseius finitimus and as allomones for Phytoseiulus persimilis. Both Phytoseius finitimus and Amblyseius gossipi were strongly attracted to T. uriticae, moderately attracted to C. pulcher, and neutral towards E. dioscoridis, suggesting a preference hierarchy. Dicke and Groeneveld (1986) also demonstrated a hierarchical structure of preference by Amblyseius potentillae, with the highest preference for European red mite (Panonychus ulmi) followed by apple rust mite (Aculus schlechtendali) and the two spotted mite (Tetranychus uriticae).

Bruin and Sabelis (1989) reported the oviposition rate of females of Tetranychus uriticae on uninfested cotton plants that had been exposed to airborne signals from infested plants to be lower than uninfested plants that had not been exposed to such signals. Takabayashi and Dicke (1992) investigated the behavioural response of the predatory mite Phytoseiulus persimilis to volatiles from several host plants of its prey, spider mites in the genus Tetranuchus. Predators showed a positive response to volatiles from tomato leaves and lima bean leaves, whereas no response was observed to volatiles from cucumber leaves or leaves of Solanum luteum and Solanum dulcamara. They also recorded that spider mites (Tetranychus urticae) reared on lima bean leaves did respond to volatiles from lima bean leaves, while predators that had been reared on the same spider mite species but with cucumber as host plant did not respond to lima bean leaf volatiles.

Prospects for applying of this knowledge in the field of pest control are wide open. Dicke et al. (1990b) presented the following applications in current pest control programmes.

1. Using the response to the allelochemical as a criterion in selection of natural enemies for biological control. This is being used to develop biological control of the cassava green mite in Africa.

2. Using the response to the allelochemical as a criterion in quality control. This application could be made today; however, quality control programmes for natural enemies are not common.

3. Using knowledge of indirect plant defense tactics in plant breeding programmes to enhance searching efficiency of entomophages. This has been done successfully for a morphological trait of cucumber plants to control whitefly by using the parasitoid Encarsia formosa (Van Lenteren et al., 1987; Van Lenteren and De Ponti, 1990). High hair densities on leaves of cucumber varieties used in horticulture, impede host searching by the parasitoid. Biological control is not therefore successful on these varieties. Recently, new cucumber varieties with lower hair density have been selected in a cooperative effort of plant breeders and entomologists.

1.4.4 Searching behaviour

Searching behaviour of predatory mites depends on many factors among which are its nutritional requirements, its state of hunger and environmental stimuli. Foraging responses were also influenced by hunger state. Zhang and Sanderson (1992) reported that hunger and experience of the predator Phytoseiulus persimilis on different host plants affected foraging behavior, and that both the stimuli from prey and host plants were involved. It was the experience of the present generation, rather than the experience of the parent generation, that affected predator foraging behaviour. In this study, patterns of changes in predator behaviour agreed qualitatively with two predictions from the variable-response model of Vet et al. (1990), which predicts parasitoid foraging responses to stimuli in the host-finding process. Two predictions of the variable-response model are, (1) learning (or experience) that changes the response model to a stimuli also changes the variability of the response accordingly, and (2) for a given stimulus, the magnitude of the change caused by a certain experience depends on the level of the original response.

1.4.5 Web coping

The webbing made by various phytophagous mite species can act as a barrier to predatory mites unless the predator has a specific capability to overcome such barriers. Some predatory mite species have the ability to penetrate or overcome webs and capture prey. Gerson (1985) described that webbing usually hinders generalist predators (like Anystis) while encouraging specialists (i.e. Phytoseiulus persimilis). Information on how predatory mites cope with the webs of their prey was not available until Sabelis and Frank (1993) proposed, based on behavioural observations, that the ability of the Phytoseiidae to penetrate webs is related to chaetotaxy. They reported that phytoseiid species differ widely in chaetotaxy, as well as in their ability to cope with complex webs. This hypothesis was tested by studying relations between these two variables. When the soma was protected from contact with silk webbing, species experienced less hinderance from complex webs of spider mite (Tetranychus spp.) and were able to successfully reduce local populations of spider mite successfully. The setal pattern varies among different species of mites in relationship to theis ability to handle webs of Tetranychus spp. Thus, the varying setal patterns seen in different species of Phytoseiid mites may be a good indicator for selecting candidates for biological control of Tetranychus spp.

1.5 Role in biological control programmes

The characteristics of a successful acarine biocontrol agent are well-developed searching and dispersal abilities, voraciousness, a distinct preference for the pest species, (though not to the exclusion of other diets), an ability to survive pest scarcity, and a power of increase at least as high as that of its main prey. The two successful mite predator genera Anystis and Hemisarcoptes, do not quite fit into this formula, in that they do not have a distinct preference for one or a small number of pest species. These exceptions reflect the heterogeneity of acarine biocontrol agents and emphasizes the need for more research on what constitutes a good natural enemy.

1.5.1 Field colonization

Finding methods for the establishment, protection and monitoring of the beneficial predatory mites in crop fields is a important task of the researcher. Boller and Remund (1991) provided an illustrated account of methods that have been used over a number of years to establish, protect and monitor the predatory mite Typhiodromus pyri as a biological control agent against arthropod pests (mainly Acari) of grapes in vineyards in Switzerland.

1.5.2 Laboratory populations

Biocontrol agents may be either collected from the field or mass-reared in the laboratory. Having an effective mass rearing method for a predatory mite is a essential factor for its successful use in biological control projects. Piatkowski (1987) developed a method of mass-rearing the predator Amblyseius mchenziei on Acarus farris (Acari: Acaridae), a stored product pest in Poland, approximately 340 mobile individuals of the predator per litre culture were produced over a five week period. Taborsky (1988) described a different mass rearing technique for the same predatory mite species.

Temperature and relative humidity have a major effect on the development of laboratory reared predatory mites. James and Taylor (1992) studied the effect of temperature on the development of Amblyseius victoriensis in New South Wales in Australia and established the lower development threshold, upper development threshhold and day-degrees required for development stages. No development occured at 42.5oC. Mangini (1991) reported on the differential effects of vapor pressure deficit on laboratory populations of Metaseiulus occidentalis and Neoseiulus fallacis (Acarina: Phytoseiidae) reared together on Tetranychus uriticae. It was suggested that timing of releases of both species to control O. ununguis on Fraser fir (Abies frasen) in western North Carolina should be based on humidity conditions.

1.5.3 Effect of pesticides and other chemicals

Extensive use of plant protection chemicals during1950 to the present often resulted in inadvertent destruction of acarine natural enemies followed by outbreaks of phytophagous pests. In fact it was often only after pest outbreaks occured that the contribution of acarine biocontrol agents to pest control were recognised. Gerson and Smiley (1990) briefly summerised findings on the effects of insecticides and acaricides on acarine biocontrol agents. When fourteen compounds used for suppression of lepidopteran pests of citrus in California were tested for residual toxicity, fluvalinate and esfenvalinate caused the greatest mortalities to E. stipulatus and did so for up to 60 days after treatment. There was little effect on fertility by any compound (Bellows et al., 1992).

Li and Harmsen (1992) reported that application of the pyrethroid PP321 affected the phytoseiid Amblyseius fallacis and the stigmeid Zetzellia mali. In the same study, another phytophagous mite Aculus schlechtendalis was strongly suppressed by the pyrethroid lambda-cyhalothrin application. Similarly, Hardman et al. (1988) showed, the pyrethroid fenvalerate greatly influenced the predatory mite Thyphlodromus pyri. This was attributed to the toxicity of the pesticide to the mite and to its longer residual activity. The effect of pyrethroid lambdacyhalothrin application on the spatial distribution of phytophagous and predatory mites on apple was studied by Li et al. (1992) for three years and evaluated using the index of dispersion and the slope of Taylor's power low. Panonychus ulmi showed that between-tree spatial variation decreased with an increase of population densities, whereas, between-leaf variation increased with population densities. With phytophagous mites, Tetranuchus uriticae, Aulus schlendali and predacious mites Zetzellia mali and Amblyseius fallacis, between-tree variation was much greater than between-leaf variation at all field population density levels. Thus, they suggested that pyrethroid application caused P. ulmi, T. uriticae, and A. fallacis to be less aggregated and A. schlendali to be more aggregated.

In Italy (Faccioli et al.,1990), fenpropathin, fluvalinate, methomyl, and methidathion demonstrated a poor level of selectivity on beneficial arthropods (e.g. the coccinellid Stethorus punctillum and phytoseiids). In the same study, 50% reduction in Tetranychus uriticae egg consumption by Phytoseiulus persimilis and a six fold increase in abandonment of the leaf was observed when leaves were treated with fluvalinate. Continuous consumption of fenbutatin oxide-treated eggs over 5 days did not affect *P. persimilis* oviposition or egg viability (Petitt and Karan, 1991). Deng et al. (1990) reported that availability of food before and after overwintering, as well as the number of pesticide applications during the season, had been critical in influencing the population fluctuations of the predator in apple orchards of Gansu province, China.

Hassan et al. (1988) and Van Zon and Wysoki (1978) showed how diverse fungicide effects on predaory mites can be. Recent evaluation of acaricidal fungicides (i.e., fungicides that kill mites) for their effect on red spider mites (Young, 1990) revealed that none of the fungicides were highly toxic to the predatory mite *Typhlodromus pyri*; however, further work is needed to investigate the suitability of Dinocarp and Mancozeb in integrated pest management programmes. When Mancozeb and Dithanon were tested for their effects on the predatory mite *Amblyseius andersoni* Chant. (Ioriatti et al.,1993), a decrease in egg hatch that was dependant on age at time of treatment was found when eggs were treated directly with mancozeb. However, no effects on mite mortality or reproduction were observed in short-term tests with diathianon. Karg (1990) reported that predatory mite populations fell sharply in one orchard after treatment with the very toxic fungicide Afugan (pyrazophos) against powdery mildew (*Podosphaera leucotricha*), but experimental introduction of new populations were successful in re-establishing the natural enemy. Hayes et al. (1989) investigated in the laboratory and apple orchards the impact of the protectant fungicides metiram and mancozeb on *Planonychus ulmi* and the predatory mite *Typhlodromus pyri*. The results of this investigation and other published results were incorporated into a predator-prey model. In contrast to these studies, Brooker (1987) reported that the acaricide 1,2,4,5-tetrazines was highly active against

Panonychus ulmi on apples but safe to several species of predatory mites and beneficial Hymenoptera.

Foliation agents, chemicals used to induce foliation, may also have some effects on predatory mites. Redl & Fuchs (1992) investigated the effect of treating of vines with a foliation agent on predatory mite frequency. The following agents showed no effect when applied at bud burst: Oleo Basudin (oil+ Diazinon) 0.5%, sulphur colloid 2.0%, Thiodan (Endosulfan) 0.2%, Neoron (Bromopropylat) 0.16%, Aktuan (Cymaxanil + Dithion) 0.1%, Ultracid (Methidathion) o.3% and Dithane (Mancozeb) 0.3%. Only with the pyrethroids Decis (Deltamethrin) 0.05% and Baythroid (Cyfluthrin) 0.08% was the development of predatory mites slightly affected after bud burst.

When three chemical fruit thinners, carbaryl, naphthaline acetic acid (NAA) and benzyladenine (BA) were sprayed on predatory and phytophagous mites in a petridish assay and in the apple orchards, NAA had harmful effects on Zetzellia mali in both tests while carbaryl caused mortality in Amblyseius fallacis and Z. mali (Thirstlewood & Elfving, 1992).

1.5.4 Resistance to insecticides

In integrated pest control programmes insecticides / pesticides are used with other control measures. When biocontrol agents have a capability to resist pesticides, the biocontrol agent can then be used in IPM programmes which include pesticides. For example, a pyrethroid resistant strain of Typhlodromus pyri was developed in New Zealand in 1978 (Walker and Marwick, 1989). These strains have proved to be effective as biocontrol agents against Panonychus ulmi in commercial New Zealand apple orchards since 1985.

Problems can rise with pesticide resistant natural enemies if their fitness level is poor compared to susceptible individuals. Golovkina and

Aksyutova (1989) showed that females of Phytoseiulus persimilis resistant to high temperatures or the organophosphate Actellic (pirimiphos-methyle) did not differ from normal ones in fecundity, lifespan, pre-reproductive or reproductive period.

1.5.5 Prey-paralysis by mites

Most predators are reported to have venom to paralyze their prey. Tomalsky and Miller (1991) showed that females of Pyemotes tritici, a predatory mite, inject an extremely potent venom into their insect prey that causes muscle-contraction and paralysis. Females of Pyemotes tritici inject an extremely potent venom into their insect prey that caused muscle-contraction and paralysis Tomalsky and Miller (1991). Their venom was effective in a broad range of insect species. In this report, the cloning, sequencing and expression of a complementary DNA (Tox-34) encoding T*P-I, a toxin associated with the mite venom, were described. When injected with the toxin, insect (Spodoptera frugipera) cells and larvae of Trichoplusia ni showed paralysis, thus reflecting the potential application of this toxin gene in insect biocontrol methods.

1.6 Mites as biocontrol agents in apple IPM programmes

The compatibility of biocontrol agents with other pest management practices allow their inclusion in integrated pest management programmes. In Germany, Gunther & Harzer (1990) reported on the development of integrated control of weeds, pests and diseases of fruit crops (especially apples).In their report they paid special attention to the timing of applications, damage thresholds, measures against Pammene rhediella (a species that has become increasingly important), spider mite (tetranychids) and scab, and the use of insecticides and acaricides that are not hazardous to the predatory mite

Typhlobromus pyri. The importance of predatory mites in fruit production is discussed by Karg (1990). Here a sharp decline in populations of predatory mites was triggered by a very toxic fungicide. However, predatory mite populations were successfully re-established by experimental introduction of new populations into orchards.

Hoy and Glenister (1991) released Amblyseius spp to control Thrips tabaci on cabbage and reported on the results of these field releases. Reductions in thrips number were proportional to the number of mites released, but damage by thrips was unaffected. When predators were released at different times with the same number of mites each time, fewer thrips and less damage at harvest resulted. The authors suggested improvements in release timing and strategy to provide a commercially acceptable level of control. Croft and MacRae (1992) reported from field studies in Oregon that mixtures of Metaseiulus occidentalis and Typhlodromus pyri inoculated into apple trees gave as good or better biological control of Panonychus ulmi and Tetranychus uriticae than did similarly sized populations of either predatory mite alone. Thus these two predators appear to be complementary biological control agents.

1.7 Collecting / extracting mites from the field

Currie (1934) provided an early example of the field collection of a predaceous mite, the bdellid Bdellodes lapidaria, which hides under bark or fallen branches. Boards were placed in the field as mite 'traps', and two collectors, using aspirators, subsequently obtained 1000 mites per person per hour. Subsequent improvement of this method resulted in collection of 14750 Bdellodes. In a later era, Wallace (1972) developed a portable motor-operated sucking machine to collect large quantities of these mites. Recently, James et al,(1992), on the otherhand removed and recovered mites from grapevine wood material using a microwave oven which makes mites fall to the bottom of a plastic bag.

1.8 Anystis baccarum

Anystis baccarum Berlese (Acari: Anystidae), is an effective predator of small phytophages (Lange et al.,1974a). The common name of this mite, the whirly gig mite, is given because running occures in a characteristic figure eight or corkscrew pattern (Muma, 1975).

1.8.1 Occurrence and distribution

Anystis baccarum is recorded from Russia where it was predominantly found in forests with young and medium aged trees (Lange et al.,1974a; Golovach, 1988). Womersley (1933, 1942) reported that A. baccarum is the most widespread species in the genus. It is known to occur in Australia, Egypt (El-Halawany, 1990), Poland (Haitlinger, 1985), Southern England (Banhawy, 1993), and New Zealand (Ramsay,1980).

The best known closely related species of Anystis baccarum, Anystis agilis is not found in New Zealand. It is a cosmopolitan predator which lives in diverse habitats, including varied crop situations such as vineyards (Sorensen et al., 1976). Anystis species were also found in Carmel Valley and Castroville, California (Goh and Lange 1989) associated with artichoke. Otto and Halliday (1991) reported the native range of Anystis species newly named as A. wallacei is in the western Mediterranean areas of France and Spain and in north Africa.

Anystis agilis and Anystis salicinus are abundant in pasture lands and apple orchards whereas, Anystis baccarum is abundant in trees and shrubs, but also occurs in orchards (Sorensen et al., 1976; Lange et al.,1974a; Golovach, 1988; Womersley, 1933, 1942)..

1.8.2 Biology and lifecycle

The best known species within the family Anystidae is Anystis agilis Banks. It has two annual summer generations in Nova Scotia and California (Lord, 1949; Sorenson et al., 1976). Anystis baccarum, on the other hand, is the most abundant and widespread species in the genus. In Russia, it has two generations per year, but three generations have been observed in hot years (Lange et al., 1974a). Russians studying A. baccarum have not observed any males during their studies; however, Womersley (1942) observed male A. baccarum from Buckland Park, South Australia.

1.8.3 Adults

Adults of Anystis baccarum are relatively large mites (its size in Russia is 1.5-2.5 mm) and are very mobile (Lange et al., 1974). In Australia, dimensions of males and females are reported as, length of 990μ, and 910μ, and width of 1,083μ, and 1,040μ respectively (Womersley, 1942). Lange (1974) reported that Anystis baccarum was parthenogenetic and that gravid females laid eggs in soil litter. The life span of adult a females was 15-17 days. In Russia, Anystis baccarum lay eggs in forest litter in autumn and the pre-larvae hatch in spring (Golovach, 1988). Lord (1949) noted Anystis agilis lay eggs on the ground and the larvae move back to the apple trees. This is contradictory to the reports on A. agilis where they occure predominantly in pastures.

1.8.4 Egg

Eggs of A. baccarum are round in shape and red-brown in colour and are laid in clusters of 25-30 (Lange, 1974a). Golovach (1988) stated that a temperature of 25^{o}c and a relative humidity of 75% were favourable for the development of eggs and pre-larvae. Prolonged maintenance of eggs at 5-6^{0}c, and exposure to 25^{0}c adversely affected subsequent development. Arid conditions (R.H 15%) desiccated the eggs of Anystis agilis (Sorensen et al., 1976). Embryonic diapause is characteristic of Anystis baccarum (Golovach, 1988).

1.8.5 Pre-larva and larval stages

The prelarval stage of A. baccarum lasts 10-15 days and is immobile even though it has three pairs of legs (Lange,1974a). The prelarval stage does not feed but instead exists on the reserve of yolk in the intestine. In contrast, larvae of A. baccarum are very mobile, bright red in colour, and climb up the trunks of trees to the top to feed actively. This stage lasts 5-6 days (Lange,1974a).

1.8.6 Nymphal stages

Anystis baccarum has three nymphal stages, the proto-, deuto-, and trito-nymph, all of which bear four pairs of legs. The enclosure of molting phases within silken cocoons lasts for 1.5- 2 days Lange (1974a). The sizes of the protoymph deutonymph and tritonymph have been reported to be 0.21 - 0.30 mm, 0.45 -0.55 mm and 0.75 -0.99 mm, respectively (Lange, 1974a). The three nymphal stages lasts, on average, a month.

1.8.7 Survival

Starved adult Anystis baccarum survived 7-9 days under laboratory conditions, but when fed with mites they survived for 2.5 weeks (Golovach, 1988). Totally deprived adults of Anystis agilis lived ca. 2 days, while those offered water or exudate of young grape leave, lived ca. 4 days or 6 days, respectively (Sorensen et al., 1976).

1.8.8 Cannibalism

Baker (1967) reported that all stages of Anystis agilis are cannibalistic and that even newly hatched larvae promptly feed on eggs or pre-larvae in the same vial. Lange (1974a) reported the prelarval stage exists on yolk reserves in the intestine.

1.8.9 Effect on environmental factors on development

Golovach (1988) stated that favourable conditions for the development of Anystis baccarum were temperatures of 23-27 ^{0}c and relative humidities of 70- 80%. A sudden decrease in temperature below 15^{0}c delayed appearance of larva by more than a month.

1.8.10 Predatory behaviour

Anystis baccarum have been observed running on the surface of leaves searching for prey. As they encounter prey the prey is immediately grabbed with the pedipalp and tarsi (Lange,1974a). Once the prey is located and held by the forelegs, feeding commences by sucking.

1.8.11 Leaf morphology on predatory behaviour

When Lange et al. (1974a) studied the effectiveness of Anystis baccarum in controlling spider mites infesting soya bean land black currant leaves, Anystis was more effective on glabrous berry leaves than on hairy soybean leaves. Studies done in Berkeley, California, revealed that prey searching of Anystis agilis occurs along leaf veins and edges with feeding initiated after tactile contact with prey (Sorensen et al., 1976).

1.8.12 Effect of prey on predatory behaviour

Baker (1967) claimed, although Anystis agilis feed on a wide range of prey (see Table 3), the kind of food taken depends on the stage of the mite and the type of prey available. Chance encounter seems to govern Anystis agilis's search for food, thus seems likely that its value in the control of any one species depends upon the numerical relationships of all species upon which it feeds (Lord, 1949).

1.8.13 Prey preference

Lange (1974a) states that the prey preference of A. baccarum depends on developmental stage and the size of prey. For example, larvae and protonymph of Anystis baccarum prefer larvae and eggs of spider mites. However, Baker (1967) reported that certain larger mites, Pergamasus crepsipes (L.) and Leptus trimaculatus (Haem.), escaped predation by A. baccarum due to their size. Mostafa et al. (1975) cited indirect evidence that A. agilis showed a preference for citrus thrips over citrus red mites and aphids. However, Anystis that fed only on spider mites were sluggish and uncoordinated, as compared to predators offered insect prey (Sorensen et al., 1976). Sorensen et al. (1976) also observed several prey defences of varying effectiveness: evasive speed, colonial webbing and integumental shielding. For example, shielding of the posterior end of leaf hoppers, Erythroncura elegantula, by the tegmina restricts attack of these prey to head the or abdominal sterna. Collembola (Poduridae) evaded predation by jumping, but were easily subdued when chilled, while Drosophila adults avoided capture by flight but succumbed upon chilling or wing removal. Dense webbing of Tetranychus uriticae minimized predation.

1.8.14 Use of Anystis species as biocontrol agents

Adult female Anystis agilis consumed an average of ca. 39 adult female Tetranychus urticae or 6 nymphal leaf hoppers (Erythroneura elegantula) per day, in vineyards in California (Sorenson et al., 1976).

Anystis salicinus (which was recently renamed Anystis wallacei, Ralph, 1992) was released to control populations of red-legged earth mite in Australia in 1965 (Otto, and Halliday, 1991), but was slow in dispersing and preferred to feed on other prey when given a choice. Mis-identification of this species as Anystis baccarum by a European taxonomist at the beginning set Australia's biological control programme back nearly 30 years. Anystis salicinus is also an effective predator of Halotydeus destructor and of the lucerne flea, Sminthurus viridis (L.)(Collembola) (Meyer and Ueckermann, 1987).

Anystis baccarum greatly reduced spider mite infestations on blackberries and soybeans within 2 and 5-7 days, respectively. Initial predator: prey ratios were 1:30 or soyabeans, 1:50 on blackberries (Lange et al., 1974a). Releases of predators to pest-infested plants were made immediately after predators were obtained in large numbers from oak and pine litter (Lange et al., 1974b).

1.8.15 Rearing

Although predatory mites such as the Phytoseiidae spp. have been reared on a commercial scale (Overmeer, 1985), no Anystidae spp. have been reared on a large scale. The long generation time and cannibalistic habits of A. agilis precluded it from consideration as a candidate for mass-rearing in the laboratory (Sorensen et al., 1976).

Table 3. Prey species of Anystis.

Prey Order	**Common name**	**Scientific name**	**Source**
Acari	fruit tree spider mite		Baker (1965)
	European red mite		
	–	Paratetranychus pilosus	Baker (1965)
	–	Tydeus spp.	"
	–	Cyta spp.	"
	–	Eupodes spp.	"
	–	Chambotes borealis	"
	–	Arytaina genistae	"
	–	Psylla spartiophila	"
	–	Stalia major	
	cattle tick	Boophilus microplus	El Banhawy et al., (1993)
	two-spotted mite	Tetranychus urticae	"
Coleoptera	Broom beetle	Phytodecta olivacea	Baker (1965)
Collembola	–	Folsomia cavicola	Baker (1965)
	–	F. candida	"
	–	F. distincta	"
	–	Isotoma spp.	"
	–	Entomobrya nivalis	"
	–	E. pulchella	"
	–	E. multifasciata	

Prey Order	**Common name**	**Scientific name**	**Source**
Diptera	house fly	*Musca domestica*	Baker (1965)
	–	*Stomoxys calcitrans*	"
	–	*Lucilia sericata*	"
Hemiptera	pea aphid	*Acyrthosiphon pisum*	El Banhawy et al., (1993)
			Sorensen et al., (1976)
	leaf hopper	*Erythroneura elegantula*	Baker (1965)
	coccid	*Matsucoccus josephi*	"
	strawberry aphid	*Pentatrichopus fragaefolii*	
Lepidoptera	caterpillars	–	"
	eye spotted bud moth	*Spilonota ocellana*	"
Siphnoptera	lucerne flea	*Sminthurus viridis*	El Banhawy et al., (1993)
Thysanoptera	cereal thrips	*Limothrips cerealium*	El Banhawy et al., (1993)
	thrips	–	Baker (1965)

The most suitable method for transfering A. salicinus interstate and possibly locally, would be in the egg stage (Micheal et al., 1991). Managing populations already present in agricultural systems would be an alternative to rearing in the laboratory and inoculative releases.

Laboratory and field studies carried out on A. baccarum in the Ukraine (Golovach,1989) indicated that cereal aphids (Schizaphis graminum), melon aphids (Aphis gossipii) and spider mites (Tetranychue uriticae) developing on smooth -leaved plants were prey species.

1.8.16 Collecting Anystis mites from the field

For experimental sampling of Anystis mites, a portable insect suction (D-vac) sampler has been used (Sorensen et al.,1976; Banhawy et al., 1993). Three different methods were employed by Lange et al. (1974b) to obtain large numbers of Anystis baccarum: egg clusters deposited in pine oak litter were collected by sieving the litter, moving mites were collected using a sweep net provided with a collecting bottle at its bottom, and adults ascending and descending tree trunks. Individuals and farmer groups in Western Australia have commenced establishing colonies of A. salicinus by collecting tens of thousands per hour using a suction machine from pastures and transfering them to a protected area (Micheal et al., 1991).

CHAPTER TWO

Interactions between Anystis baccarum and larvae of Epiphyas postvittana, a pest of apples

2.1. Introduction

Predatory mites are an important resource for the biological control of pests of agriculture. Mites in the family Phytoseiidae are examples of how effective predator mites can be in biological control programmes. Strains of four phytoseiid species found in New Zealand, Amblyseius fallacis, Typhlodromus occidentalis, Typhlodromus pyri, and Phytoseiulus persimilis, have either developed resistance to organophosphate insecticides in the field or have been artificially selected for resistance and are currently being used as predators of spider mites of family Tetranychidae (Collyer, 1982). Integrated mite control, based on the organophosphate insecticide resistant strain of Typhlodromus pyri is a widely accepted strategy for control of European red mite (Panonychus ulmi) in New Zealand apple orchards. The predatory mite Amblyseius cucumeris, which is produced commercially for use as a biological control agent for thrips in greenhouses in Europe (The Netherlands, Denmark, England), Canada, and USA, was recently reported as a potential biological agent to control New Zealand populations of thrips (Workman et al.,1994).

The attributes of a successful acarine biocontrol agent (reviewed by Gerson and Smiley, 1990) are well-developed searching and dispersal abilities, voraciousness, a distinct preference for the pest species (and its relatives), an ability to survive pest scarcity, and a reproductive capability at least as high as that of its main prey. The successful phytoseiid mites mentioned above have many of these characteristics. However, a disadvantage of being a specialist feeder is that survival may be minimal in times of scarcity of specific hosts. Generalist predatory mites have an advantage here: in innoculative release programmes of a biological control agents, survival of the generalist feeder in the field is more secured than the specialist feeder (Gerson and Smiley review,1990). In spite of this possible advantage, generalist predatory mites have received less attention than specialists because the advantages of being a specialist are still thought to outweigh the disadvantages.

Mites in the family Anystidae are important predators. They are soft-bodied, long-legged, and free-living and prey on mites and small insects (Womersley, 1942; Gerson and Smiley, 1990). Immature and adult stages of *Anystis* are all reported to feed on prey (Lange et al., 1974a). *Anystis wallacei* was introduced to Australia from France in 1965, and has reduced populations of the red-legged earth mite, *Halotydeus destructor*, in pastures in western Australia (Michael et al., 1991; Ralph, 1992). At present, scientists in Australia are working on improving methods for spreading *A. wallacei* populations. Collecting mites using a suction apparatus and releasing mites to distant fields appears to be very successful (Ralph, 1992). Anothe species, *Anystis agilis*, is considered to be an important predator of *Tetranychus urticae* in Californian vineyards (Sorensen, 1976); however, researchers concluded that the manipulation of this species as a biocontrol agent was not feasible because of its generalist feeding habits, long generation time, prey-size discrimination and inability to cope with dense webs made by prey *Anystis baccarum* was reported to be an effective predator against small insect pests and mites of blackcurrant and soyabean in Russia (Lange et al., 1974a); however, no evaluation has been made of the use of this species as a biological control agent on a commercial scale.

During sampling programmes for leafroller larvae (tortricid pests of apples) in an apple orchard in Palmerston North, large numbers of *Anystis baccarum* (Plate 1) were discovered living alongside light brown Apple moth, Epiphyas postvittana larvae (hereafter refered to as LBAM larvae), in a shelter belt of acacia, Acacia rewa (Leguminoseae: Sub family Mimosoidae). Epiphyas postvittana is a native of Australia and is believed to have originally infested native evergreens such as acacias (Clark, 1970), but has been recorded feeding on a wide range of plants, including 73 species belonging to 28 families (Danthanarayana, 1975). The objectives of this study were to investigate whether Anystis baccarum feeds on LBAM larvae and the nature of this predator-prey relationship. Objectives included the study of several factors endogenous to the mite, such as level of starvation and experience with its prey on feeding behaviour of Anystis. The impact of several factors exogenous to the mite such as age and density of larvae, webbing by larvae and defence behaviour of larvae on feeding behaviour of Anystis baccarum were also examined in my study.

Plate 1. Anystis baccarum feeding on a neonate larva of Epiphyas postvittana

2.2 Materials and Methods

2.2.1 Mites and Insects

All experiments were conducted in the laboratories of the Department of Plant Science at Massey University, Palmerston North, between October 1993 and February 1995. Mites used in experiments were collected by aspirator from an acacia hedge shelter belt planted next to a block of apple (Royal Gala and Granny Smith) trees in the Massey University Fruit Crops Unit. Specimens of mites were sent to Dr. J. G. Charles, Crop and Food Research Centre, Mt. Albert, Auckland and were identified as Anystis baccarum. Because we were unable to identify the life stages of Anystis baccarum, the largest of the adult mites collected (1.1-1.125 mm) were selected for the experiments. Collected mites were held individually in flat bottom glass vials (75 x 25mm) with a polystopper. The stopper was pierced to provide aeration and was covered with a piece of filter paper, cut to cover the top of the stopper, which prevented escape of larvae or mites. Hot glue from a Glu Gun HG-3 (Bostik, China) was used to attach filter paper to the stopper.

Mites were collected from the acacia hedge 48 hours before the experiment commenced. Collected mites were given a large number (n=15) of neonate larvae for 24 hours (this number was predetermined by the experiment on daily consumption) to bring them to uniformity of gut contents, and then starved for 24 hours before using in experiments. Exceptions to this general procedure were experiments with different levels of starvation of mites. Predators and larvae were kept in a constant environment chamber at 20^{0}C and 55.25 ± 7.27 % RH and 12:12 (L:D) photoperiod with lights on at 6.00 am.

Epiphyas postvittana (LBAM) larvae were obtained from eggs of an ongoing laboratory culture at Hort-Research, Mt. Albert Science Centre, Auckland. Larvae were reared for experimentation in plastic vials (7.5 x 1mm) filled with 1.5 ml of an artificial diet (Singh, 1974) and secured by a cotton plug. Larvae were moved by the following method. A camel's hair brush gently touched the larva to encourage it to spin down on a silken thread. By touching the brush to the silken thread the larvae could then be moved to the experimental setup. Head capsule width and length of larvae were measured under the stereomicroscope fitted with eyepiece micrometer. A stationary larva in the feeding tube was positioned along the micrometer scale and measured to the nearest 1/10 of mm.

Statistical Analysis Software (SAS Institute Inc., Cary, NC, USA,1987) was used for all analyses.

2.2.2 General characteristics of mite feeding

To determine daily consumption rate, ten whirly gig mites collected from the acacia hedge at the Massey Fruit Crops Unit were held in separate flat bottom glass tubes (75 x 25mm) in a controlled environment chamber. At the end of the 24 hour starvation period, 20 neonate LBAM larvae were introduced to each vial. Ten vials with 20 neonate larvae in each vial were used as controls. The body length and head capsule size of all larvae were measured before the experiment. Twenty four hours after introduction of the larvae, the number of live larvae left in the vials were counted. To determine the daily consumption of larvae by weight of mites, the weight of 10 mites and weight of 10 neonate larvae of LBAM were measured on a Mettler AE 163 electronic weighing scale (Mettler Instruments AG, Switzerland) and averaged.

To determine the rate at which Anystis consumed leafroller larvae, ten whirly gig mites were held individually in 75 x 25 mm glass vials and starved for 24 hours. At the end of the 24 hours, 10 neonate larvae of light brown apple moth were introduced into each vial. The timer was started when the first larva was captured and the time of beginning and completion of feeding of each larva recorded. Observations carried on until each mite completed feeding on three neonate larvae.

The survival of mites given no food was investigated as follows. Ten whirly gig mites housed in separate vials were starved for 24 hours. Each mite was then given 15 LBAM neonate larvae. At the end of 24 hours, the remaining live and dead larvae were removed from the vial. Thereafter mites were deprived of food and water. Every 24 hours vials were checked for death of mites.

Cannabalism was studied by collecting ten whirly gig mites from the acacia hedge and holding mites in separate vials for 24 hours at 20^{0}C. At the end of the starvation period, one more mite was introduced to each of five vials and one light brown apple moth larva was introduced to each of the other five vials (control). Every 24 hours thereafter, the status of the larva or mites in the vial was recorded.

2.2.3 Effects of starvation and prey density on mite foraging

Two experiments were conducted to study the relationship between starvation and walking speed and the combined effects of starvation and prey density on foraging behaviour. In the first experiment, whirly gig mites from acacia were kept in separate vials in a controlled environment chamber. The four experimental treatments were 0, 24, 36 and 48 hours. Ten mites were tested for each treatment. Here all mites were collected on the same day and reared on neonate LBAM larvae in the laboratory. Mites of each group of treatments were fed adlib before starvation for the required number of days. All mites were tested on the same day. The behavioural arena consisted of a filter paper (15 cm diameter) attached by hot glue to the flat bottom of plastic dish (15 cm diameter) which was itself placed in the bottom of a larger plastic container (22 cm diameter). This larger plastic container was then filled with 7 cm of water so that the water formed a moat around the filter paper but did not wet it. Mites were released to the arena and video recorded (Panasonic NV-FS 100 EA video cassette recorder, Panasonic Model Wv BL 200 video camera, super VHS video cassette). Each mite was observed for 10 minutes. The observations were done under constant light intensity (3.2 lux) of fourteen full-spectrum composition fluorescent tubes (36 W, 2300 lm, 1.2 m long) (Biolux, Hamburg). Video tapes were replayed at one frame per second and walking tracks were marked on acetate sheets with the position of the mite at each second and resting points also being marked. Walking tracks of several mites were not included because of complicated patterns (n=5) or no movement of the mites during observation period (n=2). Distances were measured by running a calibrated Scouts' Planimeter on the track between the rest marks. The average walking speed was calculated by measuring the length of the track that the mite walked per unit time. Data were analysed as an unbalanced completely randomised design.

The second experiment was a 2 x 2 factorial design with two levels of starvation of the mite and two densities of prey. The two levels of starvation were no starvation (ie, fed ad lib on the day of the experiment) and 3 day starvation, while the two levels of prey densities were 1 larva and 5 larvae of LBAM. Thus, the 4 treatments were: (1) 3 days of starvation of mite and 1 larva as prey (2), 3 days of starvation of mite and 5 larvae as prey (3), no starvation of mite and 1 larva as prey, and (4) no starvation of mite and 5 larvae as prey. An apple leaf was mounted at an angle of 45^0 on 4 x 4x 6 cm block of florafoam (Floral life, Inc. Illinois) which was glued inside a plastic container using hot glue, and covered with water up to the level of the leaf stalk. Prey were then released to the leaf. One minute later, a mite was released onto the leaf. The time of the first predator-prey encounter (mite contacting larva) and times of captures of larvae were recorded using a stopwatch. Observations continued until capture of one larva or up to 15 minutes. Observations of damaged mites and mites that dropped to water were discarded. Twenty replications were done of each treatment over two days. Observations were done in a random order of treatments within a single day. Due to missing values in the data set, analysis of numbers of encounters was conducted using a unbalanced randomized block design. Computed values of number of encounters per minute were used in the analysis.

2.2.4 Location of foraging activities and the influence of experience

Two experiments were run to quantify where mites forage on apple trees, how foraging time relates to resting time and the influence of feeding experience on foraging location. Fifteen mites were captured from the acacia hedge at the Fruit Crops Unit, fed to satiation, and then held for 24 hour starvation period under constant environmental conditions. "The Observer" software for behavioural research (Noldus Information Technology, The Netherlands) was used for the data collection and analysis, together with an event recorder, the Psion organiser 11 -handheld computer (International Business Machines Corporation). Two classes of information were recorded using the Observer: location and behaviour. Location was recorded as branch, leaf or fruit while behaviour was recorded as either walking or resting.

An insect-free apple shoot trimmed to one fruit and one leaf was mounted in a plastic basin (24 cm diameter x 10 cm deep) using a florafoam (4 x 4 x 6 cm) glued to the bottom of the container. The container was filled with water to a level where the florafoam was covered and formed a moat around the branch. The water acted as a barrier preventing mites from leaving the shoot. A mite starved for 24 hours was released at the top end of the shoot and observed for a maximum of fifteen minutes. At the end of each observation, the surface of leaf, branch and fruit were peeled. Peelings were then placed on an area meter LI-3100 Area meter (LI-COR, inc. Lincoln, Nebraska, USA) to measure surface area. The experiment was run using a completely randomised design. Data for one mite was not used because the mite fell into the water 450 seconds into the observation.

To investigate the influence of experience on foraging behavoiur of Anystis baccarum the same experiment was repeated after mites were given a feeding experience on either the apple branch, leaf and fruit. Observations were done on treatments selected randomly. A mite starved for 24 hours was released to the same setup as before (apple branch trimmed to one fruit and one leaf) and recorded for location and behaviour for 10 minutes. The Psion Organiser loaded with the same configuration programme used for the previous experiment on location of foraging activities was used for recording. The mite was given a neonate larva at the location of treatment (leaf, branch or fruit) until it is captured and start feeding. No recording was done during the time mite was feeding on the larva. Soon after completion of feeding, recording continued for 15 minutes. Twelve replications of each treatment was done over three days. Thus 12 observations before feeding and 12 observations after feeding were recorded. Two shoots were used to release mites for observations. The surface area of branch, leaf and fruit of each shoot were measured using LI-3100 Area meter (LI-COR, Inc. Lincoln, Nebraska, USA). Data over three days were analysed as completely randomised block design.

2.2.5 Effect of larval age and webs on mite feeding

Two experiments were done to study the preference of A. baccarum for age/size of LBAM larvae. For the no choice test, larvae were either neonates (ca. 0-12 hrs old) or were reared on artificial diet for 5, 7, 9 , and 16 days in separate vials. The head capsule width and length of each larva were measured. Fifty mites collected from the acacia hedge were held for a 24 hour starvation period. One mite was released to each vial containing larvae. Larvae were checked every hour between the hours of 6 am and 6 pm.

In the choice test, LBAM larvae were either neonates or were reared on artificial diet for 3 days or 5 days. Again the body length and head capsule width of all larvae were measured. One larva of each of the three age groups was introduced to a vial (75 x 25 mm) containing a 24 hour starved mite. Larvae were checked every 30 minutes between the hours of 6 am and 6 pm. Ten replications were done.

The effect of LBAM webs was investigated by rearing twenty LBAM larvae on artificial diet for 5 days. At day 5, the webs of 10 vials were destroyed using a camel's hair brush. Ten vials with LBAM larvae in webs were held as a control. Twenty four hours later a starved mite was introduced to each vial. Larvae were checked every hour between the hours of 6 am and 6 pm. Webs built by the mites in no web group were destroyed at the checking time. This same experiment was repeated using 2, 4, 6, 8 day old of LBAM larvae with and without webs. Ten replications were used for each treatment.

2.2.6. Behavioural responses of LBAM larvae to attack

The behavioural responses of LBAM larvae to attack by Anystis mites were quantified by introducing a single mite into a vial containing a larva and recording the behavioural responses of the larva to contact with the mite. By using larvae of different ages, I also examined age-related changes in behavioural responses to mite attack.

Predators were kept under controlled conditions for 24 hours of starvation. LBAM larvae of 1, 4, and 8 days of age reared on artificial diet were used for the experiment. Thus, six treatments of the experiment were: (1) one day old larva with a web, (2) one day old larva without web, (3) four day old larva with a web, (4) four day old larva without a web, (5) eight day old larva with a web, and (6) eight day old larva without a web. In the treatments without webs, webs were removed using a camel's hair brush before introducing mites. Twelve replicates were done of each treatment. A 24 hour starved predator was released into each vial containing a larvae. The first encounter between the larva and mite was recorded using a video camera fixed to a stereomicroscope. The vials were positioned in the stereomicroscope in a way that the larva was always in the top surface of the vial to provide a suitable environment for any of the responses. Behavioural responses were grouped into the following categories: (1) spin- a fall accompanied by spinning a silken thread, (2) wriggle- body movement with a twisting action, (3) walking away from the mite but not in a straight line, (4) quick walk straight backwards or forwards, (5) jerk- a sudden, rapid swing of body to both sides, and (6) nil response- continuation of the behaviour already in progress. The video was replayed and used to record the first behavioural response of larva when contacted by the predator or when in the presence of the predator.

In treatments without webs, the first response of the larva when contacted by the predator was recorded, while in the treatments with webs, the first response of the larvae when the mite was contacting the web was recorded. For each observation responses were expressed as percentage of the total number of responses recorded in that treatment. The effect of age/webs on response percentage was determined using the Kruskal-Wallis test (Sokal & Rohlf, 1981) using Statistical Analysis Software (SAS Institute, 1991).

2.3 Results

2.3.1 Preliminary observations

Anystis baccarum were found throughout the year on acacia (Acacia rewa) (Leguminoseae, Sub family- Mimosoideae) in an apple orchard located at the Massey University Fruit Crops Unit. Mites were also occasionally found on alder (Alnus glutinosa and Alnus viridis) (Family: Betulaceae) trees growing next to the acacia. On calm sunny days mites were found walking on foliage and branches and on acacia and apples were sometimes observed feeding on small insects, such as nymphs of leafhoppers, apple leafcurling midge larvae and adult dipterans. In the laboratory on adult Hessian fly. On windy days mites were found in cracks and crevices of the main trunk of acacias and in those areas of the smaller branches sheltered from direct winds.

2.3.2 General characteristics of mite feeding

At 20^0C, the average daily consumption rate of Anystis baccarum was 11.5 ± 2.68 neonate LBAM larvae (range 6 -15 larvae). In terms of weight of prey consumed, mites consumed 124% of their body weight per day. The mean length and the head capsule width of neonate LBAM larvae were 1.484 mm 0.231 mm, respectively.

When individual starved mites (n=10) were placed in a vial with 10 neonate LBAM larvae and observed for one hour, six of the mites consumed three prey within the hour, while three and one of the mites consumed only 2 or 1 prey during the hour, respectively. The mites that consumed two or three larvae during the hour were used to estimate mean time between feeds and the duration of each feed. Mean time between feeds of 24 hour starved Anystis baccarum was 155 seconds ± 142 seconds, with a minimum of 1 second, and a maximum of 525 seconds (Table 4). The predator spent 1106 seconds ± 309 seconds time feeding on a neonate LBAM larvae of Epiphyas postivittana. In all observations except replicate three, mites fed until only the exoskeleton of the larvae remained. In replicate number 3, the mite fed on its first larva for 470 seconds and then stopped feeding before the contents of the larva were consumed. After being fed on, this larva did not move again, being either dead or paralysed. When this same mite fed on the second larva, feeding took a longer time (1395 sec.) than usual.

Table 4. Time between feeds and mean duration of feeding of Anystis baccarum, with neonate larvae of Epiphyas postvittana as prey.

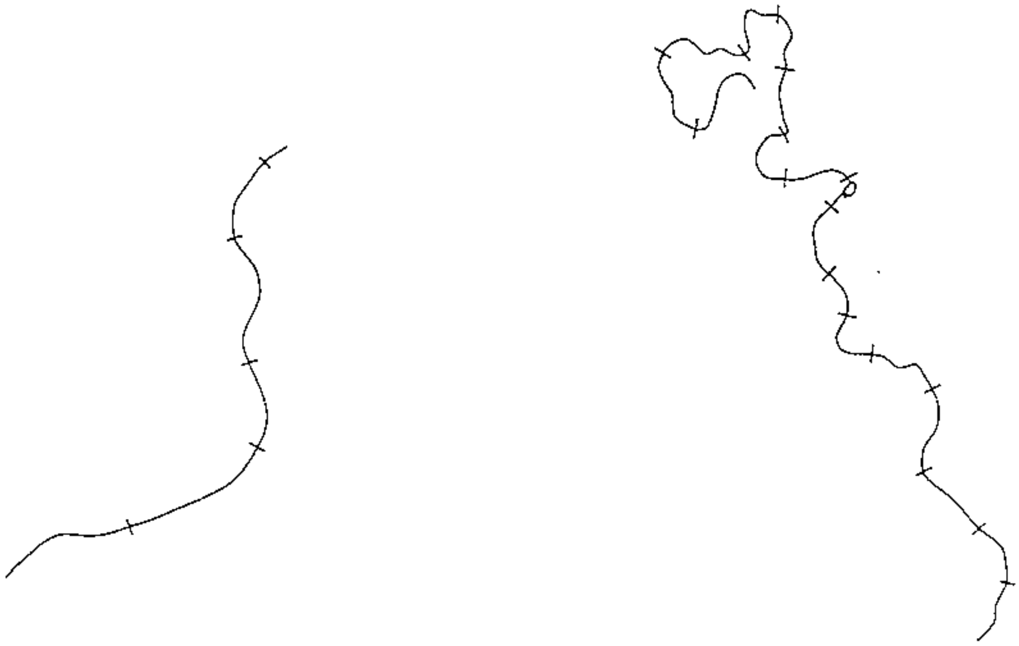
Observation	Number observed	Minimum Time Seconds	Maximum Time Seconds	Mean ± SEM Seconds
Time duration between feeds	9	1	525	155 ± 142
Feeding Time	10	471	1680	1106 ± 309

Anystis baccarum collected from the field and then fed ad libitum on LBAM larvae for 24 hours survived for a mean of 6.1 ± 2.28 days when starved of food and water.

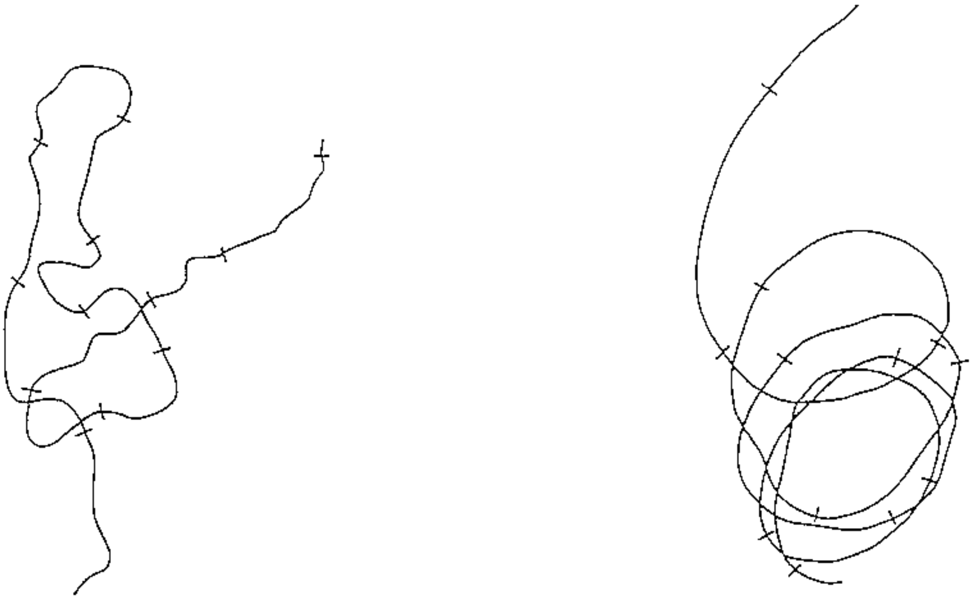
When two mites were placed together in a single vial (n=5), only one mite was left alive 48 hours later. In one of the vials, the mite was eaten during the first 24 hours of the experiment. All others were eaten in the second 24 hours.

2.3.3 Effect of starvation and prey density on mite foraging

Anystis baccarum starved for 0, 1, 2 and 3 days exhibited four main types of walking tracks on a uniform flat surface (Figure 1). Starvation had a significant effect (Table 5) on the mean walking speed of mites (one way ANOVA; F=5.37, P<0.0046).



straight run whirling pattern 1



whirling pattern 2 complicated pattern

Figure 1. Four patterns of walking tracks of Anystis baccarum on an arena of uniform flat surface of filter paper. Position of the mite at each second is marked on the track.

Table 5. Effect of starvation on mean walking speed, and percentage survival of Anystis baccarum

Days of starvation	Mean speed ±SEM cm/sec	% survival on the day of observation
0	1.105±0.537[a]	90
1	1.163±0.203 [a]	100
2	0.686±0.105[b]	70
3	0.640±0.293[b]	100

[a] Means within a column that are followed by the same letter are not significantly different at $P < 0.05$ (LSD grouping of means).

The separate and combined effects of mite starvation and prey density were investigated by introducing mites starved for two different periods of time (0 vs 72 hrs) to an apple leaf with different densities of larvae (one vs five larvae). Numbers of encounters per minute in each treatment of the experiment (Figure 2) were not significantly different relative to prey density ($F= 0.95$, $P<0.27$), level of starvation ($F= 0.53$, $P<0.47$), or prey density x level of starvation interaction ($F=3.15$, $P<0.08$).

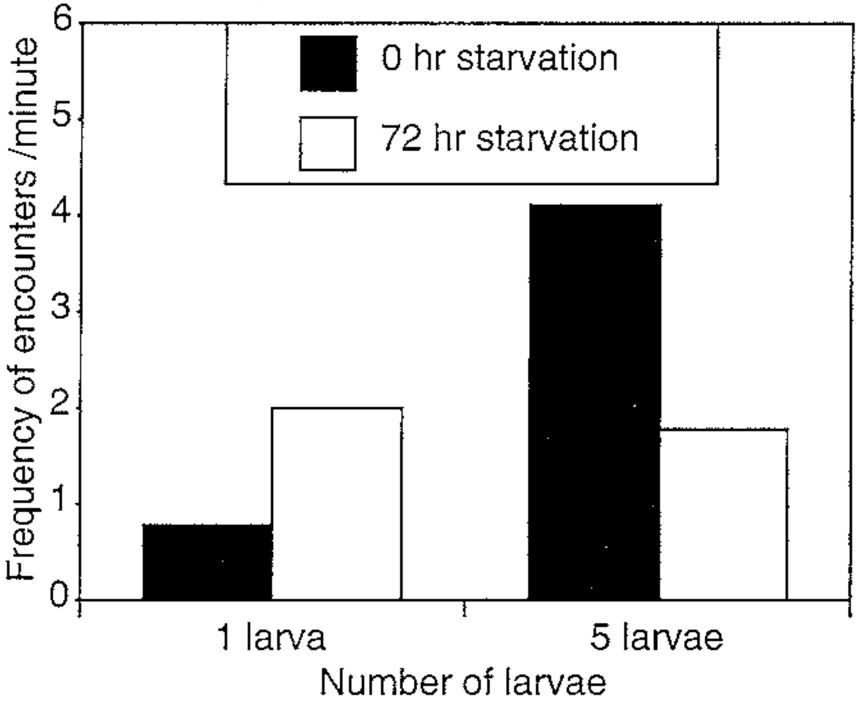


Table 6. Effect of level of starvation of Anystis baccarum and larval density of Epiphyas postvittana on captures by whirly gig mite.

Hypothesis tested	G value	df	P
starvation x larval density	0.1	1	>0.05
starvation x capture	10.21	1	<0.005
larval density x capture	10.67	1	<0.005
starvation x larval density x capture interaction	4.12	1	>0.05
starvation x larvaldensity x capture independence	18.44	6	<0.005

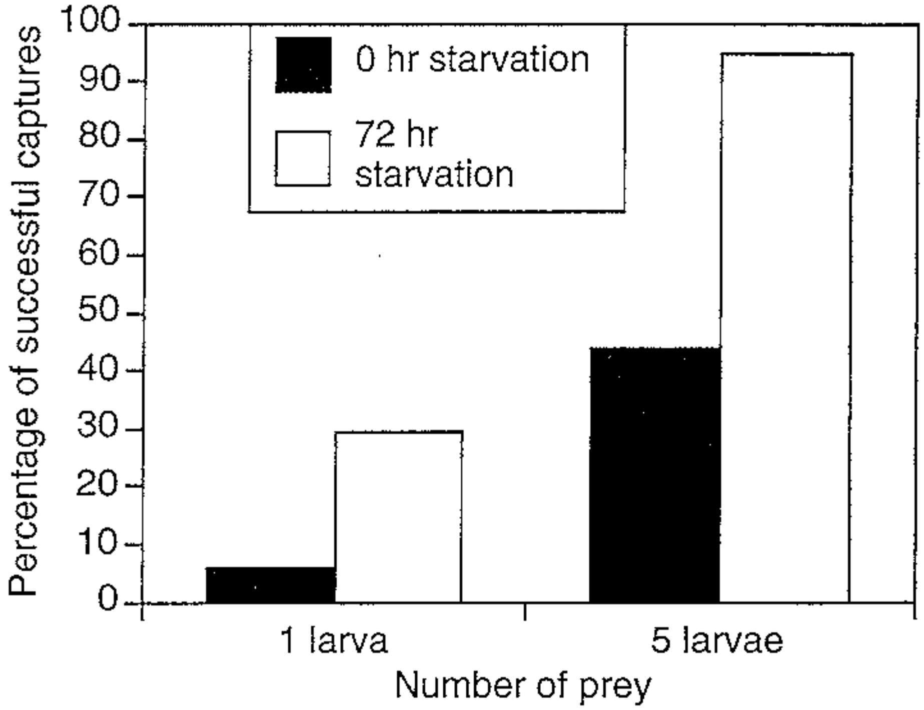


Fig.3 Percentage of E. postvittana larvae captured out of total number of encounters between A. baccarum and E. postvittana larvaeby A. baccarum by the end of observation period.

From the total number of observations the number of larvae captured by A. baccarum (Figure 3, Table 6) had significantly effected by both the level of starvation of the mite and larval (prey) density (P<0.005).

The level of starvation of the mite had a significant effect (Figure 4, Table 7) on the number of captures occuring during the first encounter of the mite and its prey larva. The interaction between level of starvation of the mite, prey density, and number of captures at first encounters is also very highly significant. Results also show that the larval density had no significant effect on number of captures at first encounter.

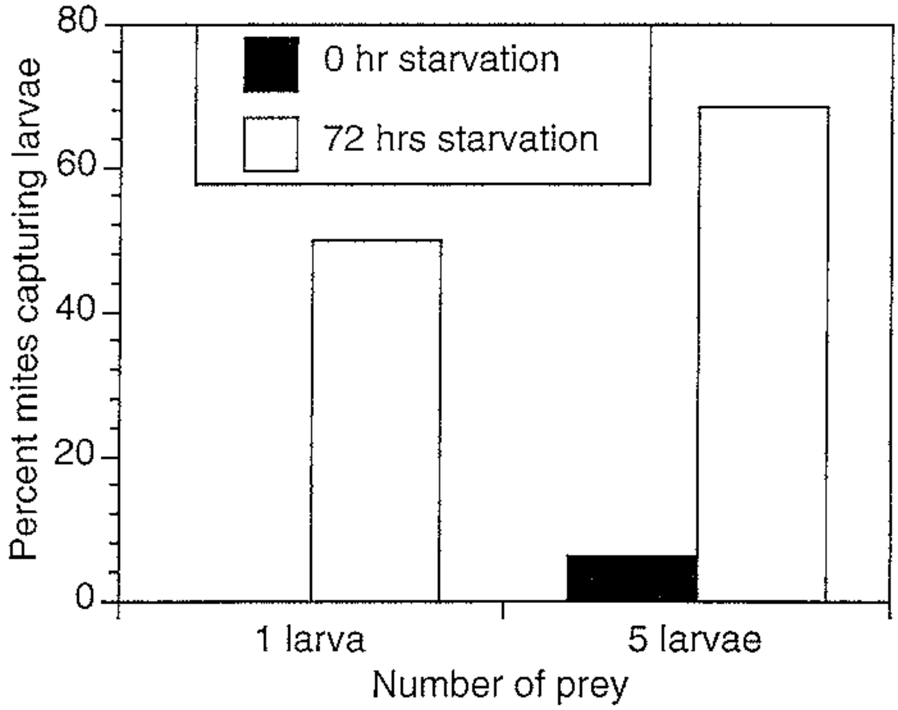


Fig 4. Percent A .baccarum captured E. postvittana larvae upon first encounbter .

Table 7. The effect of larval (prey) density of Epiphyas postivittana and level of starvation of Anystis baccarum on number of captures at first encounter by Anystis baccarum.

Hypothesis tested	**G value**	**df**
starvation*larval density	0.04	1
starvation*number of captures at first encounter	28.16*	1
Larval density* number of captures at first encounter	1.54	1
starvation* larval density*number of captures at first encounter, Interaction	1107.08**	1
starvation* larval density*number of captures at first encounter, Independence	30.74*	4

G values- ** Highly significant at P<0.001,
*significant at P<0.001

2.3.4 Location of Foraging activities

Mite foraging on apples was composed of short periods of walking and resting. Time devoted to resting periods was double that devoted to walking (Fig. 5). On average mites spent 96.43 ± 124.9 seconds walking time, and 203.57 ± 256.11 seconds resting time on apple.

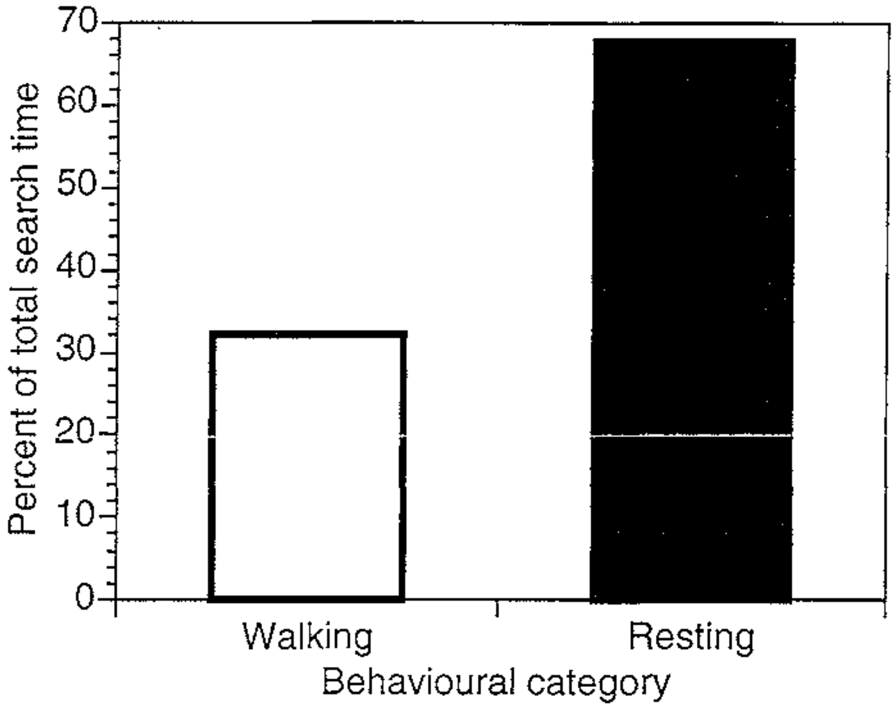


Fig. 5. Percent of searching time spent walking and resting by Anystis baccarun on apple

Mites allotted different amounts of search time to branches, leaves and fruit (Fig. 6), spending the greatest amount of time on branches (one way Anova, F= 4.63, P< 0.0156). Resting time were significantly different for different locations (F=6.29, P<0.0043). Least significant difference tests on total resting time in locations showed that Significantly more time was spent resting on the branch compared to the fruit and leaf (Fig. 7). No significant difference occured for walking times in different locations.

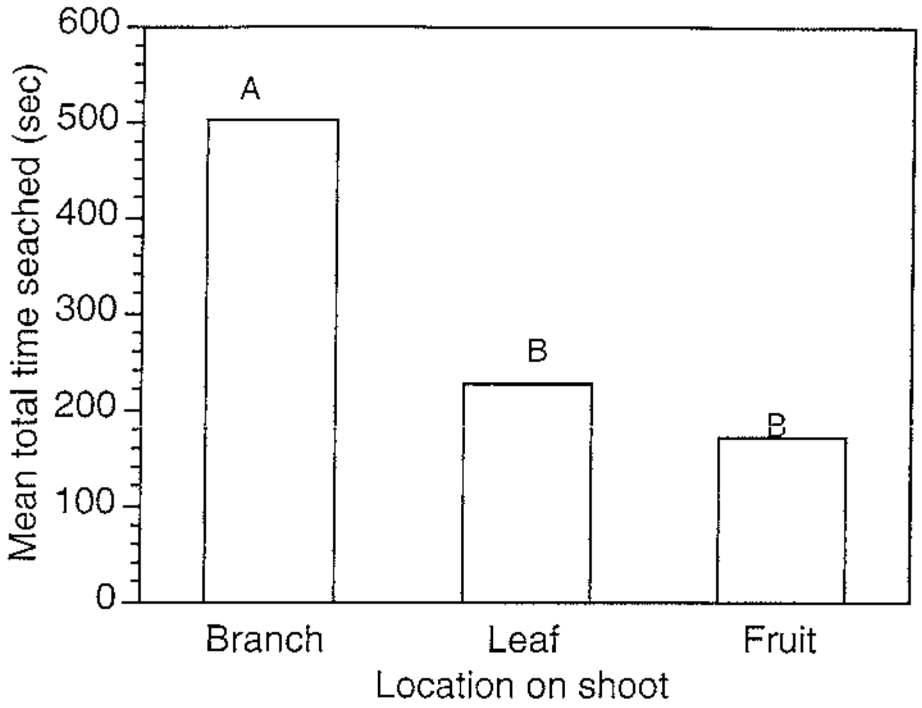


Fig. 6. Total searching time spent by Anystis baccarum on branch, leaf and fruit . Means with the same letter are not significantly different (LSD).

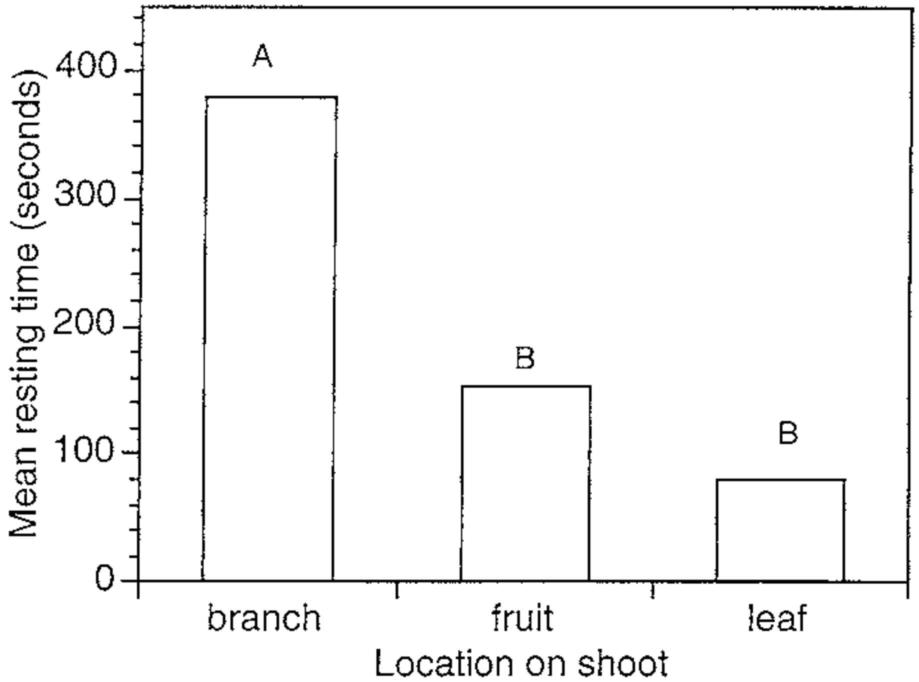


Fig .7. Mean resting time of 24 hour starved Anystis baccarum on different locations of apple shoot. Means with the same letter are not significantly different (LSD).

Due to the variability in leaf area, fruit surface area and branch area of the shoot (38, 55, and 11 sq. cm, respectively) walking and resting times were compared relative to surface areas of different locations. Location had a significant effect (Fig. 8) on walking time per unit area of location and resting time per unit area of location (one way ANOVA, F=19.25, P<0.001 for walking and F=18.71, P<0.001 for resting). When time spent in each of the on three locations (time walking and resting) were compared, both walking and resting times spent on branch were significantly higher than that of leaf and fruit .

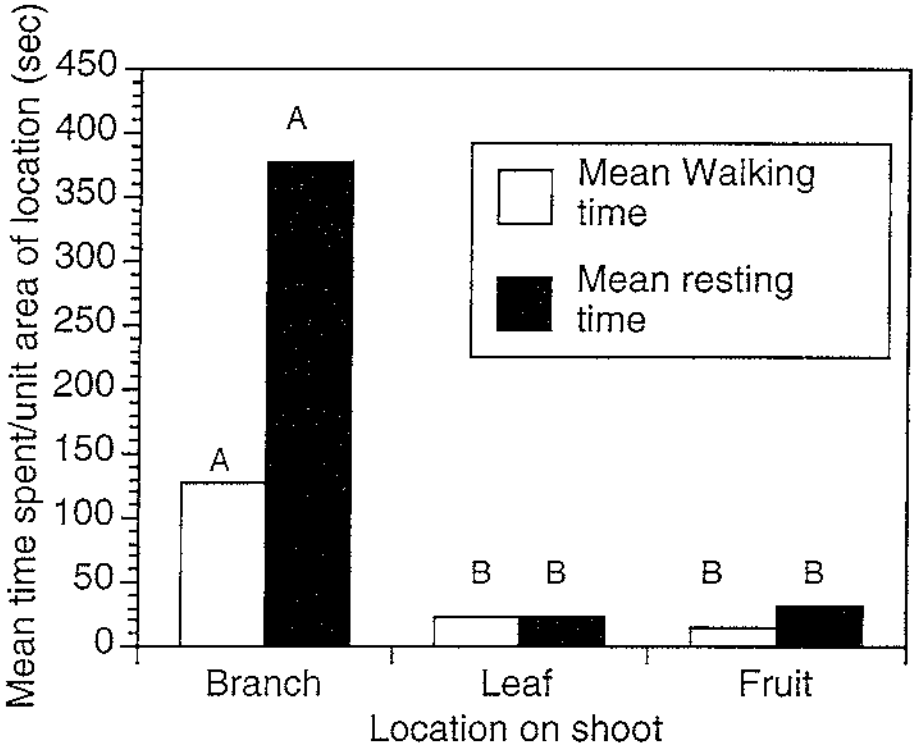


Fig. 8. Mean total walking and resting time per unit area of location spent on different locations of an apple shoot by 24 hour starved A. baccarum. Means with the same letter are not significantly different (LSD).

Before mites were fed either on branch, leaf or fruit, the allocation of foraging time to different locations was similar to that seen in the previous experiment (Fig. 6). Searching times were significantly different in different locations (F=74.71, P<0.0001), showing a greater amount of searching time on branches.

The data after feeding at a particular location were pooled and analysed to compare the total time spent feeding in locations mites had and had not fed. Mites spent significantly more time in locations they were fed (F=32.4, P<0.0001). Time spent (Fig. 9 A) and time spent per unit area (Fig. 9 B) showed similar patterns, with mites spending more time in the area they had been fed in.

Data were then analysed to compare time allocated to walking or resting after being fed in a particular location. Mites fed on the branch spent significantly more time walking and resting on the branch (Fig 10 A). Similarly, mites fed on leaf (Fig. 10 B) or fruit (Fig. 10 C) spent significantly more time walking on the leaf or fruit, respectively. Time allocated to resting in different areas did not change according to location of feeding.

When data were analysed in terms of time per unit area (Fig.11), results were similar to the results of total search time, except in the treatment where mites were fed on the fruit. Here walking and resting time per unit area of location were significantly higher on the branch rather than being higher on the fruit. In the total search data (Fig.10 C) more time was spent on the fruit after mites were fed on the fruit; however, because the fruit has a higher surface area compared to the leaf and branch, time searching per unit area was reduced relative to Fig 11 C.

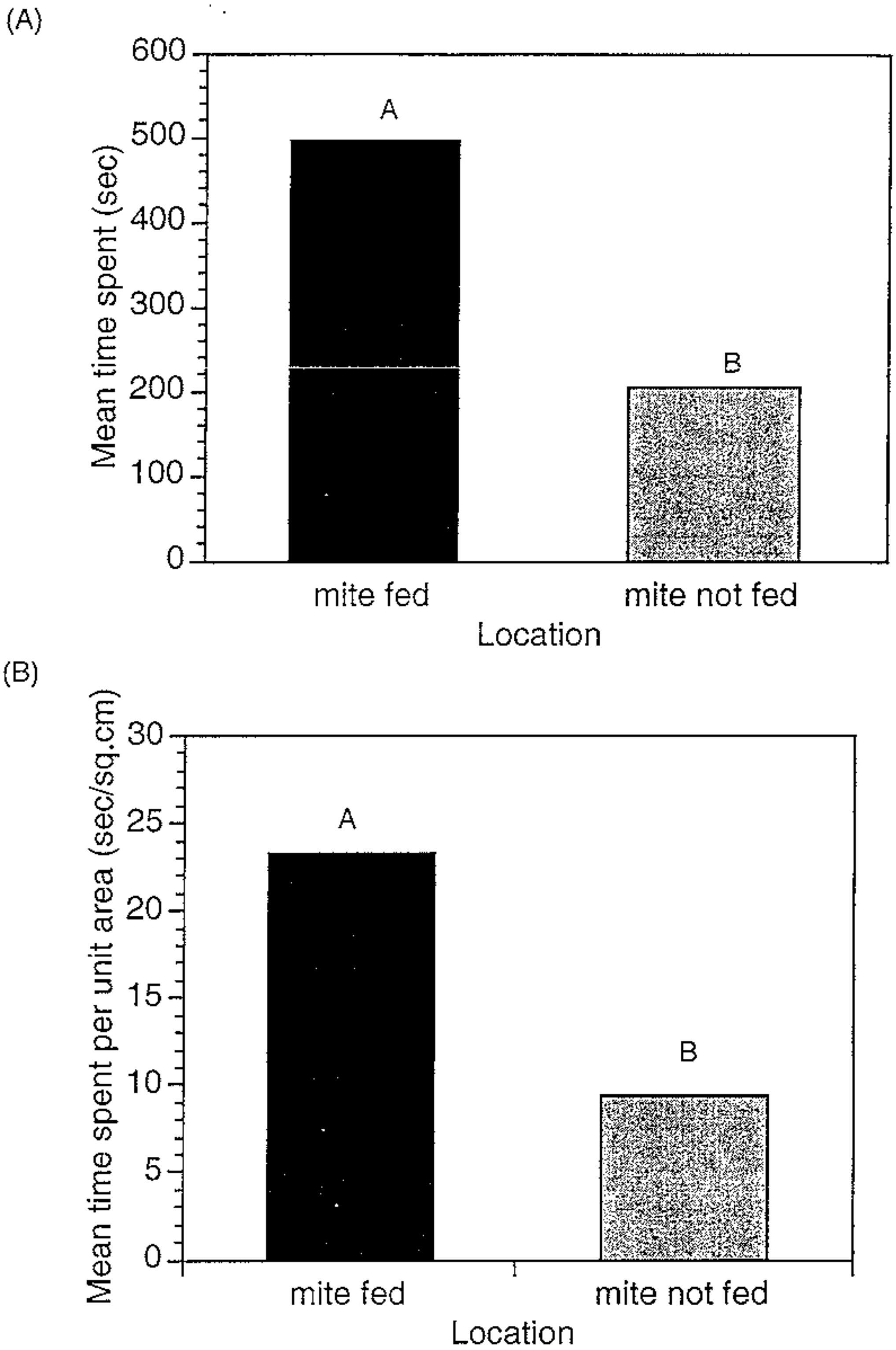


Fig. 9. (A) Mean time, and (B) Mean time per unit area spent searching by 24 hour starved Anystis baccarum on locations where prey captured. Means with the same letters are not significantly different (LSD).

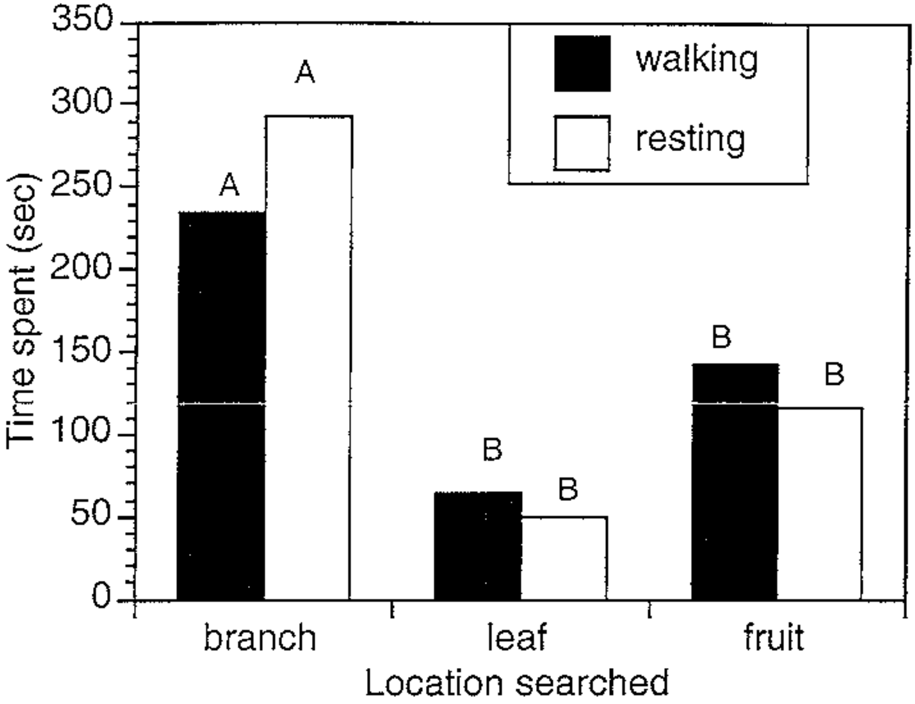


Fig. 10 (A). Total mean time spent walking and resting of 24 hour starved Anystis baccarum after feeding with a neonate larvae of Epiphyas postivittana on **branch** of an apple shoot, Means with the same letters are not significantly different (LSD).

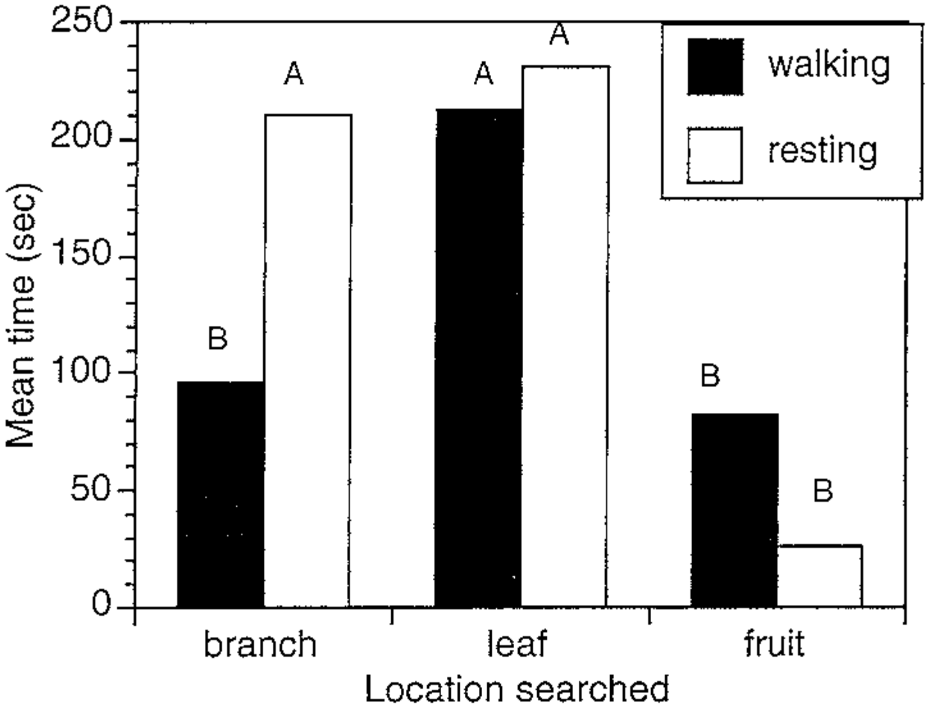


Fig. 10 (B). Total mean time spent walking and resting of 24 hour starved Anystis baccarum after feeding with a neonate larvae of Epiphyas postivittana on **leaf** of an apple shoot, Means with the same letters are not significantly different (LSD).

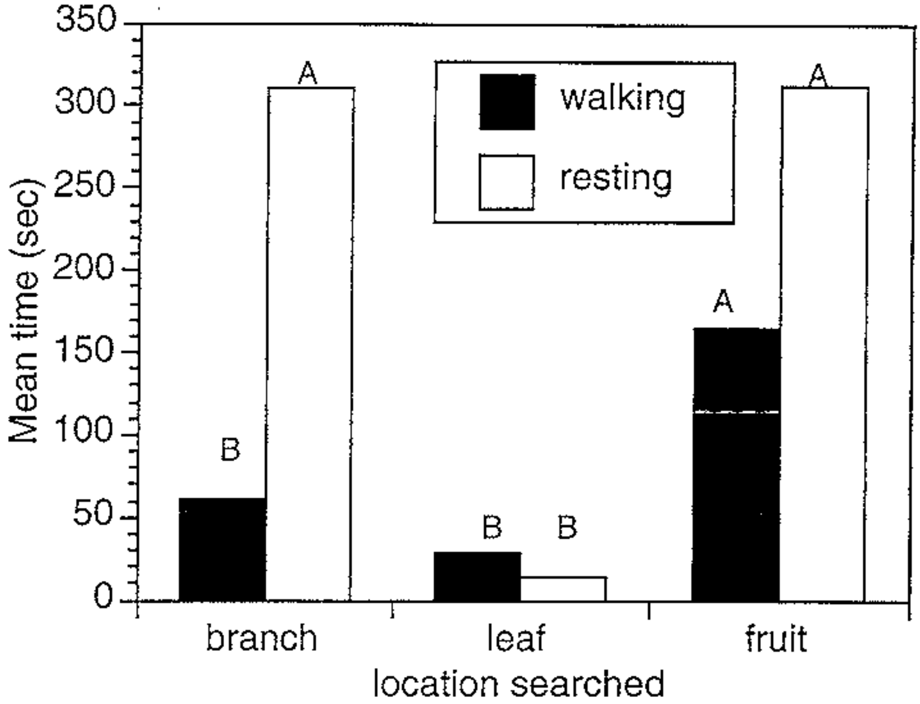


Fig. 10 (C). Total mean time spent walking and resting of 24 hour starved Anystis baccarum after feeding with a neonate larvae of Epiphyas postivittana on **fruit** of an apple shoot, Means with the same letters are not significantly different (LSD).

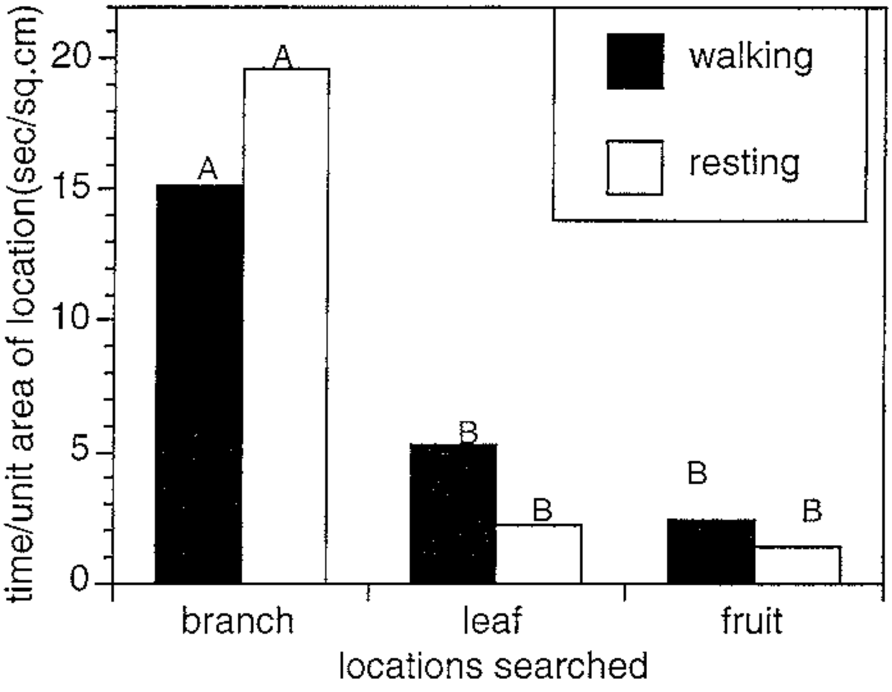


Fig. 11 (A) . Time spent walking and resting per unit area after feeding with a neonate larvae of Epiphyas postvittana, when fed on **branch** of an apple shoot. Within data for resting or walking means with the same letters are not significantly different (LSD test)

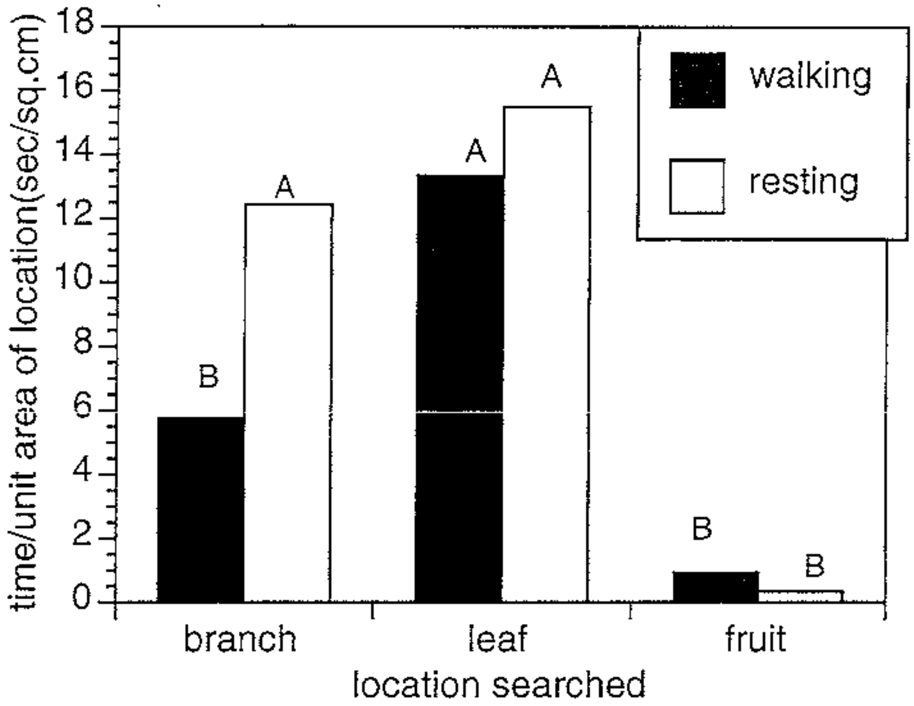


Fig. 11 (B) . Time spent walking and resting per unit area after feeding with a neonate larvae of Epiphyas postvittana, when fed on **leaf** of an apple shoot. Within data for resting or walking means with the same letters are not significantly different (LSD test)

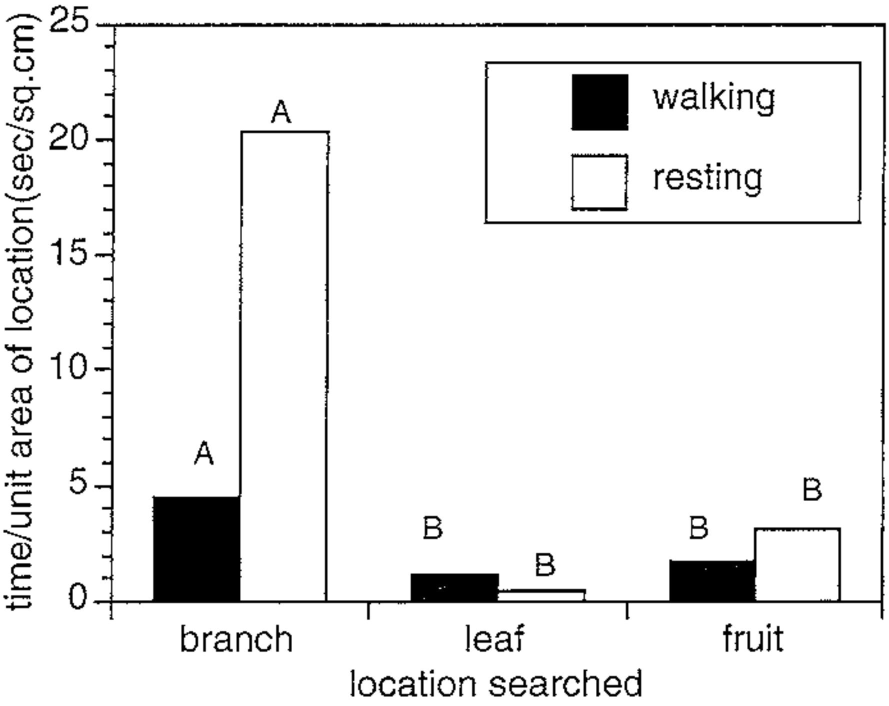


Fig. 11 (C). Time spent walking and resting per unit area after feeding with a neonate larvae of Epiphyas postvittana, when fed on **fruit** of an apple shoot. Within data for resting or walking means with the same letters are not significantly different (LSD test)

2.3.5 Effect of larval age and webs on mite feeding

When LBAM larvae of five age groups were offered to 24 hour starved mites in a no choice test (Table 8), all neonate larvae were consumed by Anystis baccarum within a mean of 3.7± 5.89 hours, whereas only a half of the total of 5 day old larvae were consumed within a mean of 2.6±1.67 hours. None of the 9 day and 16 day old larvae were consumed by Anystis baccarum within 24 hours. It was observed that 5, 7, 9, and 16 day-old Epiphyas postvittana larvae were in webs.

In a choice test in which a single mite was placed in a vial with 0, 3, and 5 day old larvae (1 of each) prey preference for the size (Table 9) was significantly different from equal preference hypothesis (significantly different Chi- square data P< 0.01) .

Table 8. Age and size of Epiphyas postivittana larvae consumed by Anystis baccarum.

Age(days)	Mean length (mm)	Mean head capsule width(mm)	Number consumed: Total observations in each treatment	Mean time (hours)
Newly hatched	1.484±0.98	0.231± 0.04	1	3.7±5.89
5	2.55±0.54	0.266±.004	0.5	2.6±1.67
7	4.34±0.95	0.343±0.07	0	-
9	6.29±0.84	0.546±0.04	0	-
16	12.38±1.21	1.02±0.27	0	-

Table 9. Prey preference of A. baccarum for three age groups of Epiphyas postvittana larvae.

Age of larvae (days)	mean length (mm)	mean head capsule width (mm)	Mean capture time (hrs)	No of first choices/ Total	P Chi- square
neonate larvae	1.4	0.21	11.1 + 7.8	7	<0.01
3	2.17±0.16	0.28±0.01	14.9±14.1	1	<0.01
5	2.86±0.12	0.28	13.5±13.8	2	<0.01

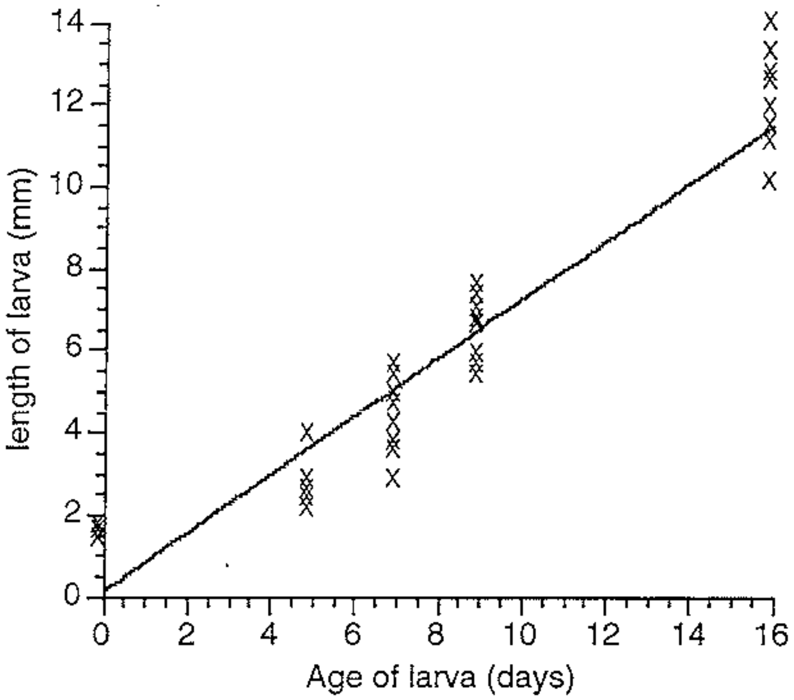


Fig 12. Relationship between age and length of Epiphyas postivittana larva.

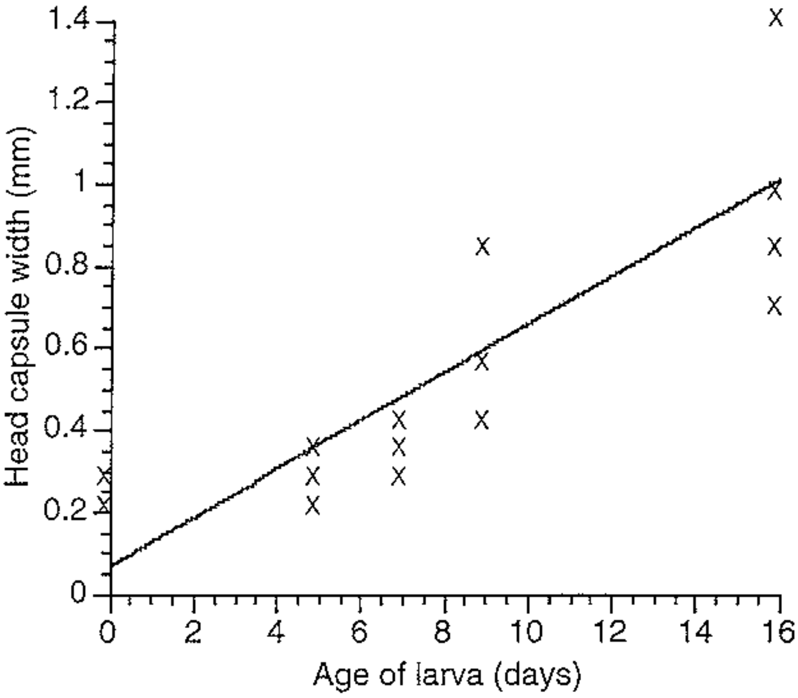


Fig 13. Relationship between age and head capsule width of Epiphyas postivittana larva

Regression analysis between age groups of neonate larvae, 5, 7, 9, and 16 days and larval length (Fig. 12) and head capsule width (Fig. 13) showed highly significant linear relationships (for larval length F=581.91, 0.0001<P, r^2= 0.92 ; for larval head capsule width, F=257.85, P<0.0001, r^2= 0.84).

When individual mites were placed in a vial with a single 5 day old larva, none of the larvae in webs were consumed, whereas 80% of the larvae without webs were consumed within the 48 hr observation period. In vials with larvae without webs, some of the larvae hid themselves near the cotton plug of the vial where they were protected from mite attack.

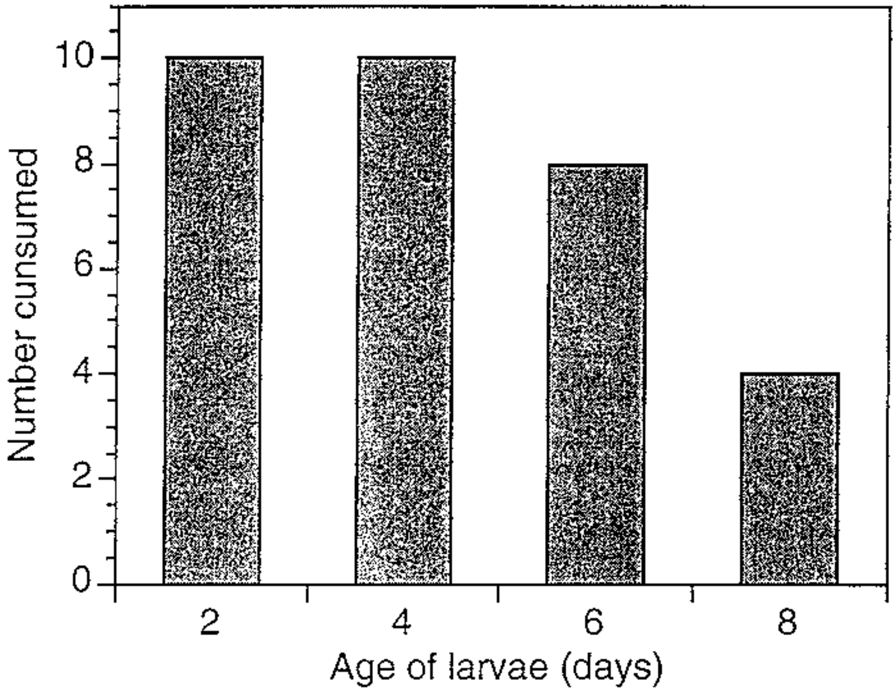


Fig.14. Percent of 2, 4, 6, and 8 days old E. postvittana larvae without webs consumed by starved Anystis baccarum.

When individual mites were placed in a vial with a single 2, 4, 6, or 8 day old larva, with or without webs, none of the larvae in webs were consumed by mites. All the larvae of 2 and 4 days old, without webs, were consumed by the mite. Mites consumed only 80% and 40% of 6 and 8 day old larvae, respectively (Fig.14). The size of larvae were largest at 8 days of age (5.25±.59 mean length); however, there was variability in size at 8 days. Of the

8 day olds without webs, it was the small larvae that were consumed by mites. (i.e., two larvae 5 mm in length and 0.375 mm of head capsule size and two larvae 5 mm in length and 0.5 mm in head capsule width). However, with 6 day olds without webs, the smallest larva (length 3.375mm and head capsule width 0.375mm) was not consumed within the 24 hours test period. Thus, size and webs are not the only important factors in prey capture.

Capture is significantly dependent on the presence or absence of webs (G test, G=29.06, df=1, P<0.001) as well as the and age of larvae (G test, G=16.27, df=3, P<0.001). When the mean capture time of the larvae of all four age groups in webs captured by the mites were plotted, against the age of larvae (Fig. 15), no correlation was shown between age of larvae and mean capture time.

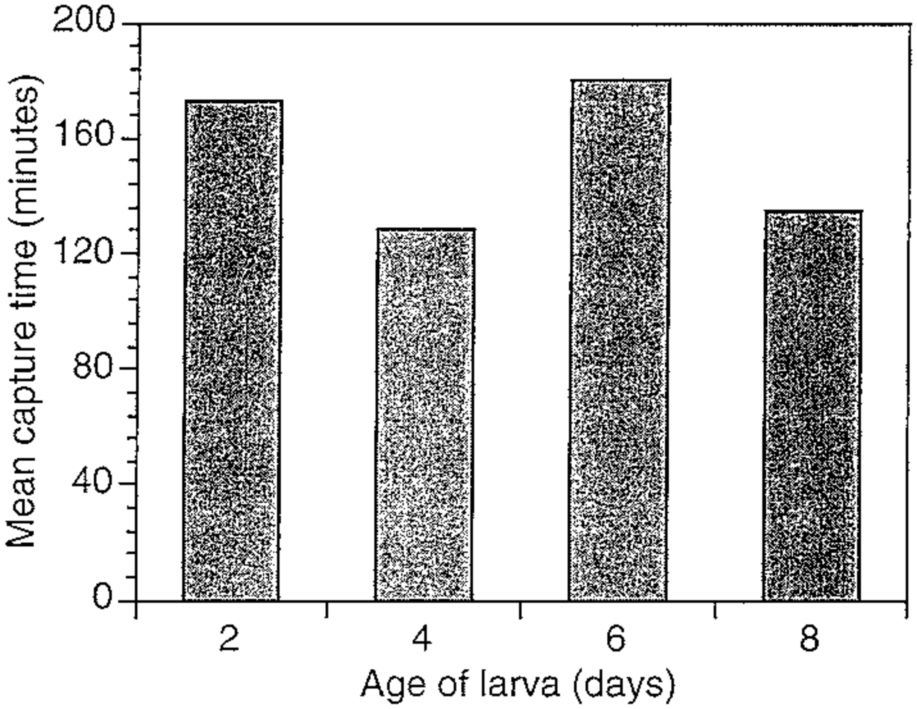


Fig.15. Mean capture time of Epiphyas postvittana larvae of different age groups by Anystis baccarum.

2.3.6 Behavioural responses of larvae to attack by mites

When responses of different aged larvae with or without webs to mite attack were observed, behavioural responses depended on both the age and webs states of larvae. Pooled data across all ages showed the following results. Spinning (F= 9.26, P<0.0035) was exibited more frequently by larvae without webs compared to larvae with webs. Wriggling (F= 5.56 P< 0.0217) was exhibited more frequently by larvae without webs than larvae with webs. In contrast, quick movements backwards or forwards occured more frequently in larvae with webs compared to larvae without a web (F= 14.72, P< 0.0003). A nil response to attack by mitea occured at the same frequency in larvae with or without webs (F=2.99, P< 0.0893).

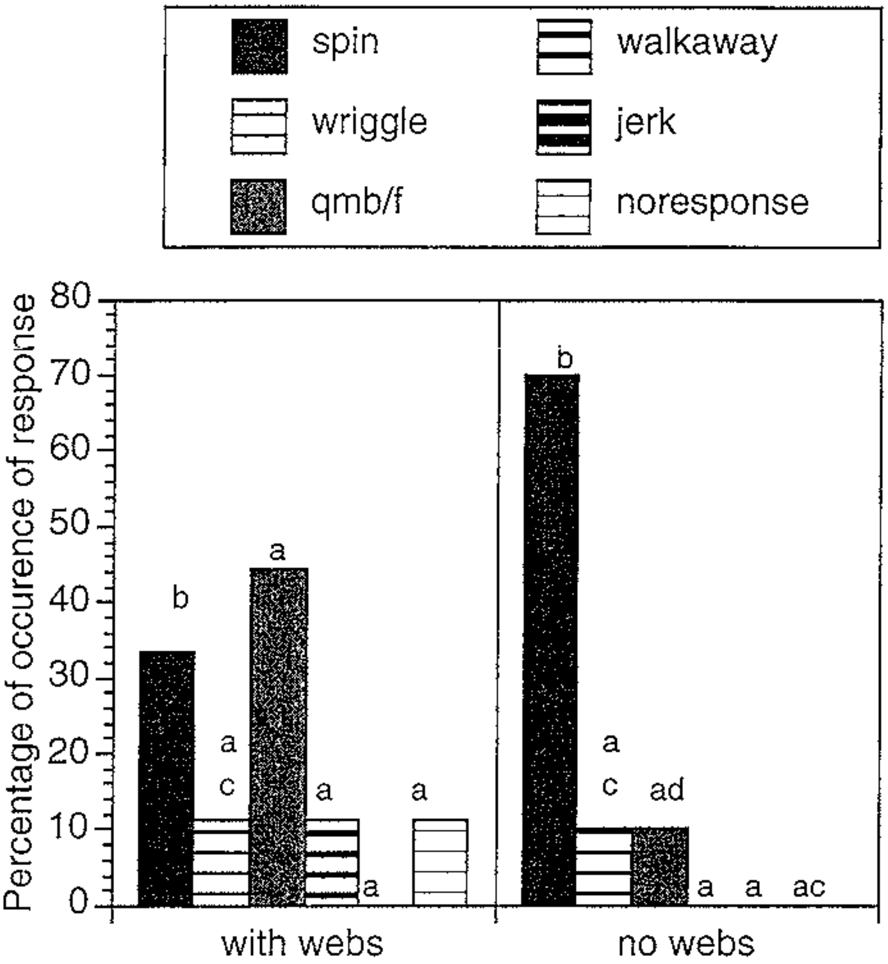


Fig. 16 (A) Percentage of occurence of response of **neonate larva** of Epiphyas postvittana to contact by Anystis baccarum. Within data for each response, percentage responses are significantly different ($P<0.05$) when followed by a different letter (LSD seperation of ranks following Kruskal-Wallis test).

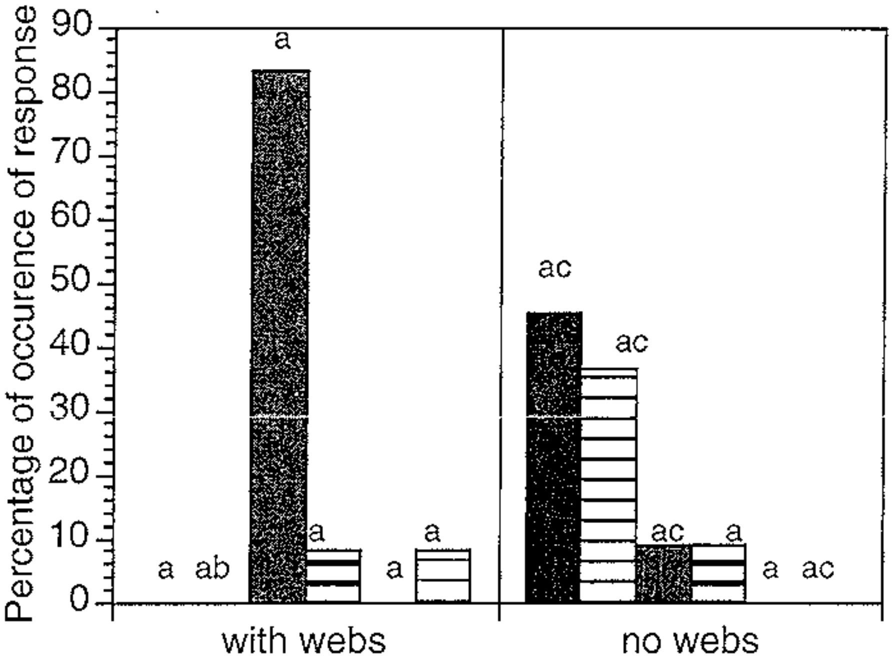


Fig. 16 (B) Percentage of occurence of response of **4 days old larva** of Epiphyas postvittana to contact by Anystis baccarum. Within data for each response, percentage responses are significantly different ($P<0.05$) when followed by a different letter (LSD seperation of ranks following Kruskal-Wallis test).

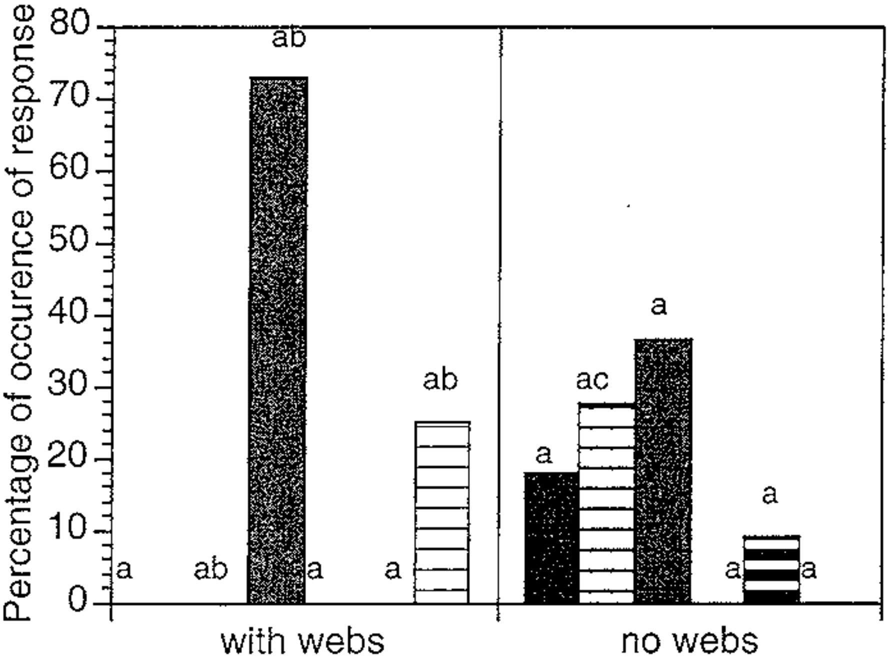


Fig. 16 (C) Percentage of occurence of response of **8 days old larva** of Epiphyas postvittana to contact by Anystis baccarum.Within data for each response, percentage responses are significantly different ($P<0.05$) when followed by a different letter (LSD seperation of ranks following Kruskal-Wallis test).

Comparisons of behavioural responses between treatments (Fig. 16 A, B, and C) show that spinning was exhibited more frequently by neonate larvae than 4 and 8 day old larvae. No significant difference occured in the spinning responses of neonate larvae with and without webs. The wriggling response occured frequently in larvae without webs, with the exception of neonate larvae. However, during observations neonate larvae tended to come out of their webs when disturbed by mite movements, and thus were capable of exhibiting spinning and wriggling responses. Four and 8 day old larvae did not emerge from webs when attacked by A. baccarum.

The larval response measured as quick movement backward or forward depended on the direction of the approach of predator. If the predator approached from behind or the front, the larvae moved forward or backwards, respectively.

2.4 Discussion

My investigations added another lepidopteran Epiphyas postvittana (Walker) (hereafter referred to as LBAM), to the existing list of prey of Anystis baccarum Berlese, a list of prey which already includes mites and insects belonging to the orders, Acari, Coleoptera, Collembola, Diptera, Hemiptera, Lepidoptera, Siphanoptera, and Thysanoptera (Sorensen et al., 1976: Baker, 1965: El Banhawy et al., 1993). A. baccarum consumed 11.5 ± 2.6 neonate larvae of LBAM and thus consumed their own weight in prey on a daily basis. Daily consumption rate of prey by A. baccarum probably does vary with the prey species; however, no recorded data are available on daily consumption rate of different prey. Larvae, protonymph, deutonymph, tritonymph and adult females of Anystis agilis Banks consumed an average of 4.1, 15.7, 38.8, 138.8 and 675.2 spider mites, respectively (Sorensen et al.,1976).

The variation in time between feeds at a given level of starvation seen from my experimental results may be attributed to chance encounter rate, and behavioural responses of larvae to avoid the enemy. Thus, if A. baccarum if encounters LBAM larvae during their initial dispersal stage, time between feeds is probably related to encounter rate which appears to be random (i.e., mites do not orient to their prey). When fed upon by mites larvae remain still. Sorensen et al. (1974) reported prey paralysis by A. agilis using venom. However, there have been no investigations of venoms in A. baccarum.

Survival of Anystis argilis adults totally deprived of food was 2 days (Sorenson et al., 1976) while those offered only water lived for 4 days. When A. agilis individuals were offered fresh plant exudates, their survival extended to 6 days. It is clear that survival of Anystis baccarum (6.1 ± 2.28 days) without food is higher compared to that of Anystis agilis. Further investigation is needed on A. baccarum starved of food but given with only water, as well as studies to find whether feeding occurs on plant exudates.

An explanation for the longer time taken by the mite to prey on conspecific mites compared to time taken to prey on larvae,may be that mites are better at avoiding attack than larvae which move slowly. The tendency of Anystis baccarum to feed on conspecifics could be an advantage or a disadvantage in biological control programmes. An advantage might be that A. baccarum can survive by cannibalism in a situation where no other prey are available. The disadvantage of cannibalism is the difficulty it causes in rearing under controlled laboratory conditions. Possibilities exist to rear cannibalistic mites under controlled densities provided they are given sufficient food. Golovach (1988) concluded that rearing A. baccarum is possible, but not easy.

It was observed, that when released to the leaf, A. baccarum search for prey by patrolling along the leaf veins, midrib, and edges of the leaf. Anystis agilis (Sorensen et al., 1976) showed the same pattern of search. This pattern of search behaviour is advantageous for mites using LBAM larvae as prey: larvae also follow the leaf veins when walking on leaves and tend to build their webs near midrib or veins (personal observation).

2.4.1 Endogeneous factors of mite-prey interaction

There is an increasing likelihood that an animal will search for a resource which it has been deprived of because depriviation increases the probability of responding to resource-related cues (Bell, 1990b). However, starvation did not cause Anystis baccarum to increase its walking speed. Instead, at 2 and 3 days starvation, walking speed decreased significantly (Table 2). Sorensen et al. (1976) observed the speed and orientation of Anystis agilis as a function of starvation (with water only). When observed on a uniform flat surface, A. agilis exhibited speeds of 105, 114, 136, and 81 cm / min after 1, 2, 3, and 4 days starvation, respectively.

Although level of starvation and prey density did not have any significant effect on number of encounters, they have a significant effect on capture of prey (Table 6). Thus, the starved mite may alter its capture behaviour and thereby increase the probability of prey capture. Starvation also had a significant effect on the probability of captures at first encounter (Table 4). In conclusion, starvation of A. baccarum enhances its prey capture rate by altering capture behaviour but not search behaviour (i.e. walking speed is not increased).

Encounters between predator and prey seem to occur randomly and are not increased by starvation. However, if encounters occur randomly increased prey density would be expect to increase encounter rate. This did not statistically appear to be the case in these experiments (no statistically significant effect) even though data showed a trend towards higher encounter rates at higher prey densities.

While foraging for prey on apples A. baccarum spent alternate periods walking and resting, but overall devoted more time to resting than walking. Mites preferred to search on branches of apple more than leaves or friuts (Fig 6.). Given that area of branches is low relative to fruit or leaves, this preference is even greater (Fig 8). However when given experience on a single larva feeding at each location mites spent more time searching the location where they were fed (Figs. 9 and 10).

Responses to plant stimuli associated with feeding at a location may change after feeding. The feeding experience of a predator can affect its foraging responses to stimuli (such as semiochemicals) from the prey, the host plant, the interaction of the two, or other host-associated organisms, in a predator-prey-plant tritropic-level interactive system (Dicke et al.,1990b; Lewis et al., 1990; and Vet & Groenewold, 1990). More studies are needed to understand the variation in predator foraging behaviour caused by experience and other sources, such as genetic differences and physiological states, and also to understand whether semiochemicals are involved in the interaction between A. baccarum and E. postvittana.

2.4.2 Exogenous factors on mite -prey interaction

Searching behaviour of insects represents the outcome of three kinds of factors (Bell, 1990a): biological characteristics of the insect and its environment, locomotory patterns, and perception of sensory information. External environmental factors determine what resources are available and the risks involved in their quest; while internal factors, such as depriviation or sexual perceptivity, determine what an individual needs at a particular time.

In the case of searching behaviour of A. baccarum, external environmental factors include protective structures built by prey. LBAM larvae start to build up their webs within 24 hours if they find a suitable site to feed, but takes longer time if they cannot find a suitable site. Larvae start feeding on plants from within the webs. Results reported here show that, webs can act as a physical barrier for A. baccarum to attack its prey, LBAM larvae. Sorensen et al. (1976) reported that dense webbing of Tetranychus uriticae minimized predation by A. agilis, a close relative of A. baccarum.

Anystis mites showed a significant preference for neonate larva when given a choice between neonate larvae, 3 day old and 5 day old larvae (Table 9). However, choice was not directly related to size of larvae: the greatest number of first choices was for neonate larvae, while lowest number of first choices was for 3 day olds. A. baccarum feeds on LBAM larvae less than eight days old as long as larvae are not in webs (Fig.14). Thus, as larvae grow, avoidance of capture by Anystis baccarum increases. Baker (1965) stated, even adult Anystis were unable to take the later stages and adults of some Collembola due to the hard exoskeleton, and a mite such as Oribatella quadrimaculata (Mich.), though small, is protected from attack by its hard exoskeleton.

The mean size of larvae increases with the age of the larvae (Fig. 13), but mean capture time has no direct relationship to the age (Fig. 15). This suggests that capture time depends on the random encounters with the predatory mite. Lord (1949) suggested that chance encounter governed Anystis agilis in its search for food so that it feeds most often upon the species it encounters most frequently. In addition to this observation, Sorensen et al. (1976) observed several prey defences of varying effectiveness against A. agilis, such as evasive movements. Webbing can also have an influence on prey selection in A. agilis.

When behavioural responses of LBAM larvae to Anystis attack were studied, spinning was the most frequent avoidence behaviour of larvae without webs (Fig. 16). The tendency to spin decreased with the increasing age of larvae. This could be due to higher pressure on the silk as the larva ages or because older larvae have other means of defending themselves. Wriggling showed a higher frequency of occurence when larvae were without webs. Neonate larvae tended to come out of the webs occasionally when disturbed, thus the spinning and wriggling responses were observed in this age group even when larvae had built webs. Larvae in webs are confined to a limited space so movement is limited. Therefore responses that involve force and pressure may be avoided by larvae in webs. Move away and jerk were the rarest responses by larvae of all groups. In contrast, quick movement backwards or forward was the most common response by the larvae in webs. Thus, larval behavioural responses to avoid predator attack varied with age and shelter situation of the larvae. Dial and Adler (1990) also showed that the responses of Heliothis zea (Lepidoptera: Noctuidae) larvae to contact by predators opponents varied with ages.

In conclusion, factors such as webs of larvae act as physical barriers to attack. With increasing age of larvae avoidance, of predator attack increases and behavioural responses to mite attack change. Endogeneous factors also have an effect on the foraging behaviour of predatory mites. Starvation increased the probability of capture during an encounter while experience of feeding on a location increased the foraging activities in that location.

2.5 Future studies

My studies revealed that larvae of the light brown apple moth, Epiphyas postvittana are a prey of Anystis baccarum. However, certain aspects of this predator-prey interactions need to be further studied if the predator is to be used in orchard pest management. The following areas need further investigation.

1. Systematics and general biology of Anystis baccarum in New Zealand, including information on life cycle and population dynamics..

2. Field studies on the impact of A. baccarum on Epiphyas postvittana larvae both in orchard crops and shelter belts surrounding orchards.

3. Relationships of A. baccarum with other prey as well as natural enemies in orchards and shelter belts.

4. Means of conservation of A. baccarum in shelter belts of orchards.

5. Possibilities of using the A. baccarum to control leafrollers on harvested apples.

6. Further investigations to understand factors causing variation of foraging behaviour caused by experience.

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